BBC

BRIAN COX & JEFF FORSHAW'S GUIDE TO THE COSMOS PART 2

SCIENCE | TECHNOLOGY | FUTURE

FOCUS

WHERE DOES TIME COME FROM?

HOW BLACK HOLES WILL SHED LIGHT ON THE FOURTH DIMENSION

Plus

ROBOT EINSTEINS

A.I.s that can think for themselves

DRIVERLESS CARS

What you need to know

DINOSAUR REVOLUTION

Radical discovery points to UK origins

SHOULD WE LET PANDAS GO EXTINCT?

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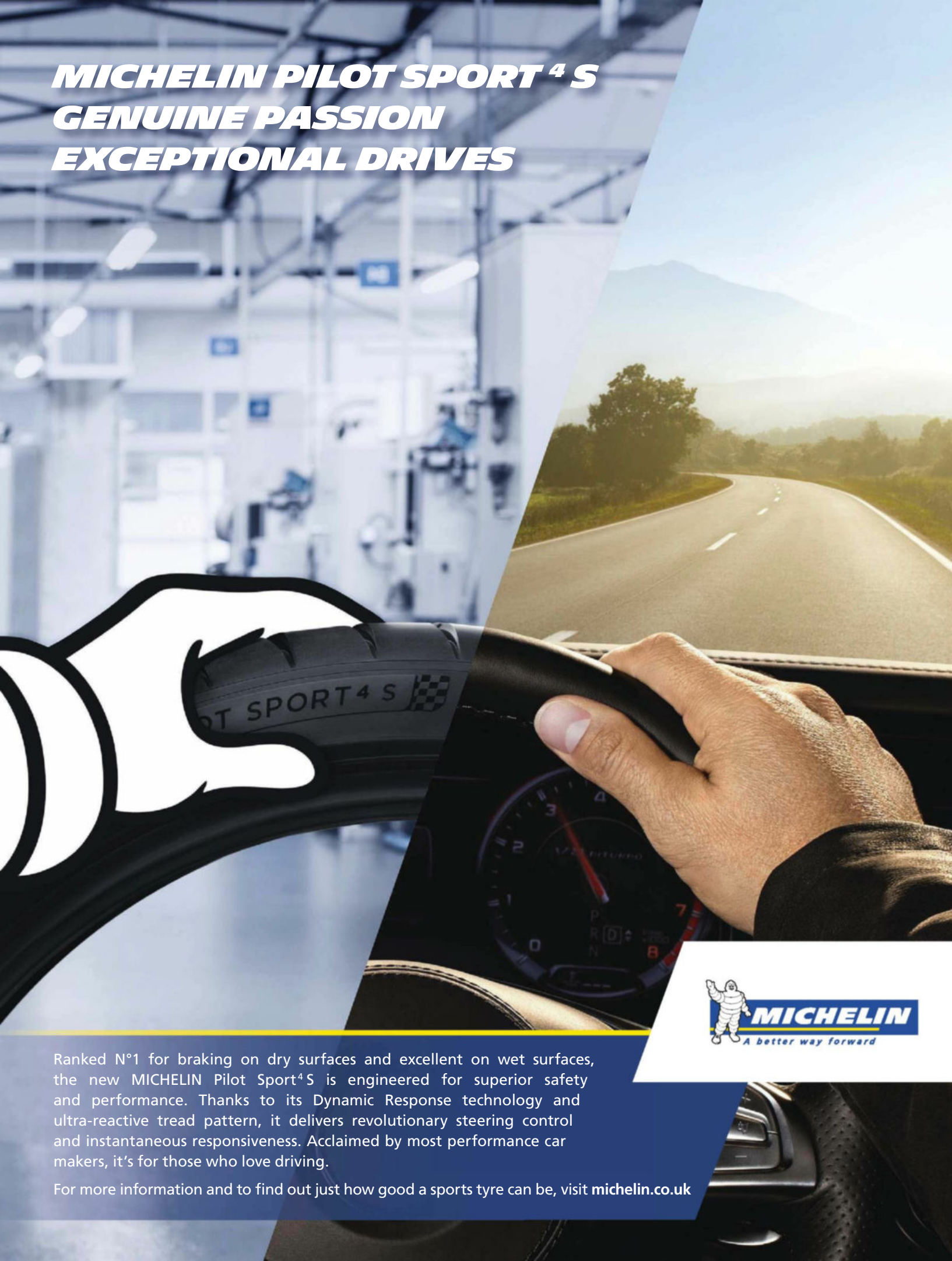

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A sloth can hold its breath for 40 minutes → p82

WELCOME

This issue, I was happy to discover I've got something in common with the philosopher Augustine. It turns out he also thought that time was a tricky concept to grasp. You see, I *think* I know what time is, but if you needed me to explain it to you, the conversation would probably end with a huff and a shrug (though if I'm being totally honest, I find quantum theory, post-structuralist philosophy and the appeal of *Mrs Brown's Boys* equally hard to explain).

But it's not just me and Augustine who are perplexed by time: around the world, scientists are trying to reach a consensus on what actually makes our Universe tick. The problem is that, on paper, all the maths describing our Universe will function whether time flows backwards or forwards – and yet it's clear time flows in one direction, from past to future. The world flows from order into disorder, but no one really knows why. Now, one professor thinks he knows where to look for an answer: at the point where two black holes collide. Turn to p38 find out how he plans to test his theory.

Also in this issue, we peer into the future of driving, or more precisely the lack of it. In the UK, autonomous cars are already scouting some of our cities, and in 2018 car manufacturers say you'll be able to buy one. So find out on p62 what you need to know before you jump into a driverless car.

Enjoy the issue…

Daniel Bennett, Editor

WHAT WE'VE FOUND OUT THIS MONTH

NASA's pioneering female scientists have been immortalised in Lego → p28

Bee larvae taste best when blanched → p93

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A frog can be used as a pregnancy test → p88

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Computer scientist Peter takes a look at how the technology behind robots is evolving, and investigates how they could learn and think for themselves. → p48

HELEN CZERSKI
Oceanographer and physicist Helen loves to explore the science of everyday life. This month: what cooked spinach tells us about chlorophyll. → p77

ROBERTO FLORE
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COVER: ANDY POTTS

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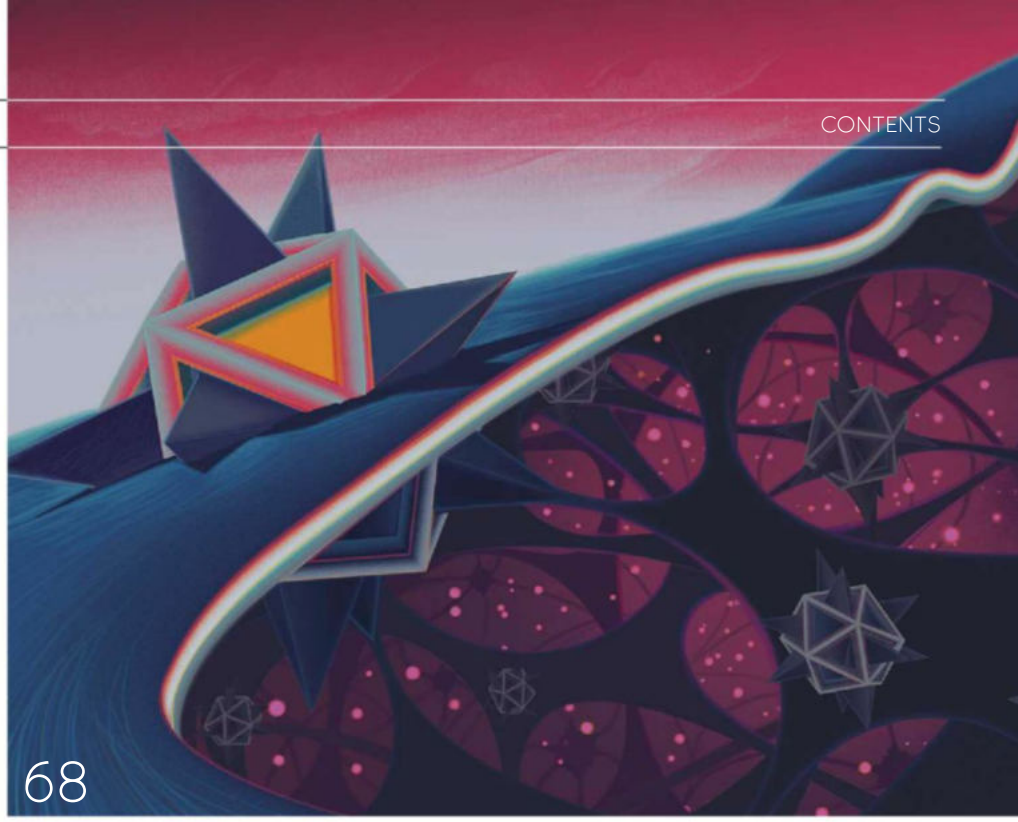

FEATURES

EYE OPENER

Robot riders

LIWA,
ABU DHABI

One group of workers that we suspect *won't* be grumbling about robots taking their jobs are the jockeys in Middle Eastern camel races. Camel racing dates back thousands of years, but the sport has a dark side. The camels were traditionally ridden by boy jockeys as young as four years old, many of whom were bought and sold as slaves, and kept deliberately malnourished.

Accordingly, since 2004 the use of child jockeys has been outlawed in Qatar and the UAE, and the camels are ridden by robot jockeys instead. Early versions of the robots were quite 'mechanical' in appearance, but now more human-like robots are used as this appears to be less distressing for the camels.

PHOTO: GETTY

EYE OPENER

Future farm

NOLI, LIGURIA
ITALY

Plunge into the waters off the coast of Noli in northwestern Italy, and you might just come across some bubble-like pods lying 6-10m beneath the waves.

These biospheres are the brainchild of scuba diver Sergio Gamberini of Ocean Reef Group, who wanted to find a viable new way of producing food. The open-bottomed biospheres, dubbed 'Nemo's Garden', provide a self-contained environment for plants to grow, and contain crops such as red cabbage, basil, garlic and strawberries.

There's no need for expensive heating and watering systems, because the ocean offers protection from temperature fluctuations, while the plants are hydrated by seawater that condenses on the internal surfaces, as seen in this image. The biospheres receive plenty of sunlight, and are protected from pests and fungi that can wipe out crops on the land.

In 2016 the biospheres were rigged up with cameras, fans, intercoms and Wi-Fi, and this year the team aims to establish the feasibility of the project.

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DISCOVERIES

DISPATCHES FROM THE CUTTING EDGE

MAY 2017 | EDITED BY JASON GOODYER

Saltopus **may be the common ancestor of dinosaurs**

PHOTO: SCIENCE PHOTO LIBRARY

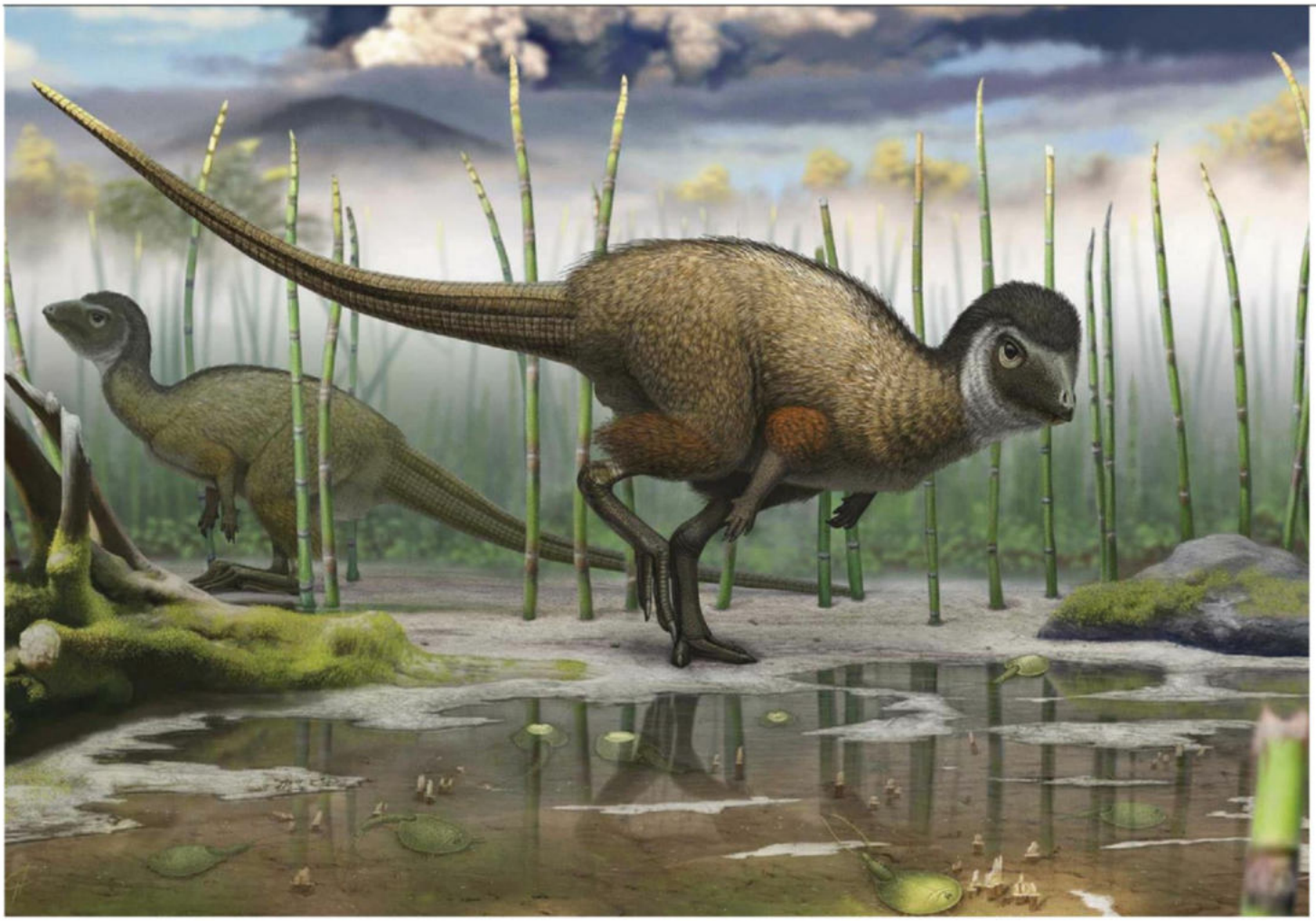
DINOSAURS

THE FIRST DINOSAURS COULD HAVE COME FROM BRITAIN

Revolutionary new research may mean we have to redraw the dinosaurs' family tree

From our green countryside to a nice bag of fish 'n' chips, we Brits have plenty to be proud of. Now, there's another thing to smile about: dinosaurs may have originated in what is now Britain. A team at the University of Cambridge has uncovered evidence that the prehistoric beasts could have evolved from a common ancestor – the *Saltopus*, which is a small Scottish specimen previously considered to be insignificant.

The somewhat controversial finding stems from the researchers' conclusion that the basic categories used to



classify dinosaur species need to be reassessed. The previous incarnation of the dinosaur family tree was drawn up by British palaeontologist Harry Govier Seeley back in the late 19th Century. He initially split dinosaur species into two main groups based on the structure of their hipbones: the lizard-like pattern of the Saurischia, and the bird-like pattern of the Ornithischia. As more dinosaurs were described, Seeley split the Saurischia into two subgroups: the sauropodomorphs, which included *Diplodocus*, and the theropods, which included the *T. rex*.

In the new analysis, the Cambridge team say ornithischians and theropods belong in the same group (called Ornithoscelida) and the sauropodomorphs in another.

"When we started our analysis, we puzzled as to why some ancient ornithischians appeared anatomically similar to theropods. Our fresh study suggested that these two groups were indeed part of the same clade. This conclusion came as quite a shock since it ran counter to everything we'd learned," said lead researcher Matthew Baron.

If correct, the study would make the *Saltopus* a candidate for the common ancestor of Ornithischia and Saurischia, perhaps meaning that dinosaurs first walked the Earth in what is now Scotland.

ABOVE: ***Kulindadromeus* is one dinosaur that will have to be reclassified, according to the new information**

EXPERT COMMENT

Dr Darren Naish

Palaeontologist

"The idea that the dinosaur family tree might require revision has received a mixed reaction. Given that the result is so novel and, to date, based on just a single study, some advocate caution and scepticism. An alternative reaction is that the proposal is not surprising given the large quantity of new anatomical data collected by Baron and his colleagues. Furthermore, a vague similarity between early ornithischians and theropods has been noted on several occasions in recent years and there have even been suggestions that some early ornithischians – notably the fang-toothed heterodontosaurids – were predators. In recent decades, studies of evolution across the tree of life have resulted in the overturning of many traditional ideas. Consequently, biologists and palaeontologists are by now quite used to the idea that cherished evolutionary models may be shown wrong as new data comes along.

Indeed, the Ornithoscelida hypothesis does better explain several observations. It might explain why theropod and ornithischian fossils share quill-like fibres that grow from their skin while fossil sauropodomorphs have – so far – always lacked such structures.

Studies are already underway to see how this new model stands up to additional tests."

PHOTO: SCIENCE PHOTO LIBRARY

PHOTOS: SCIENCE PHOTO LIBRARY / GETTY / NASA

SPACE

SATURN'S MOON HAS 'ELECTRIC SAND'

If you want to make the best sandcastle in the Solar System, you might want to head to Titan. Researchers at the Georgia Institute of Technology have discovered that grains of sand on the surface of Saturn's largest moon can become electrically charged, making them stick together more easily.

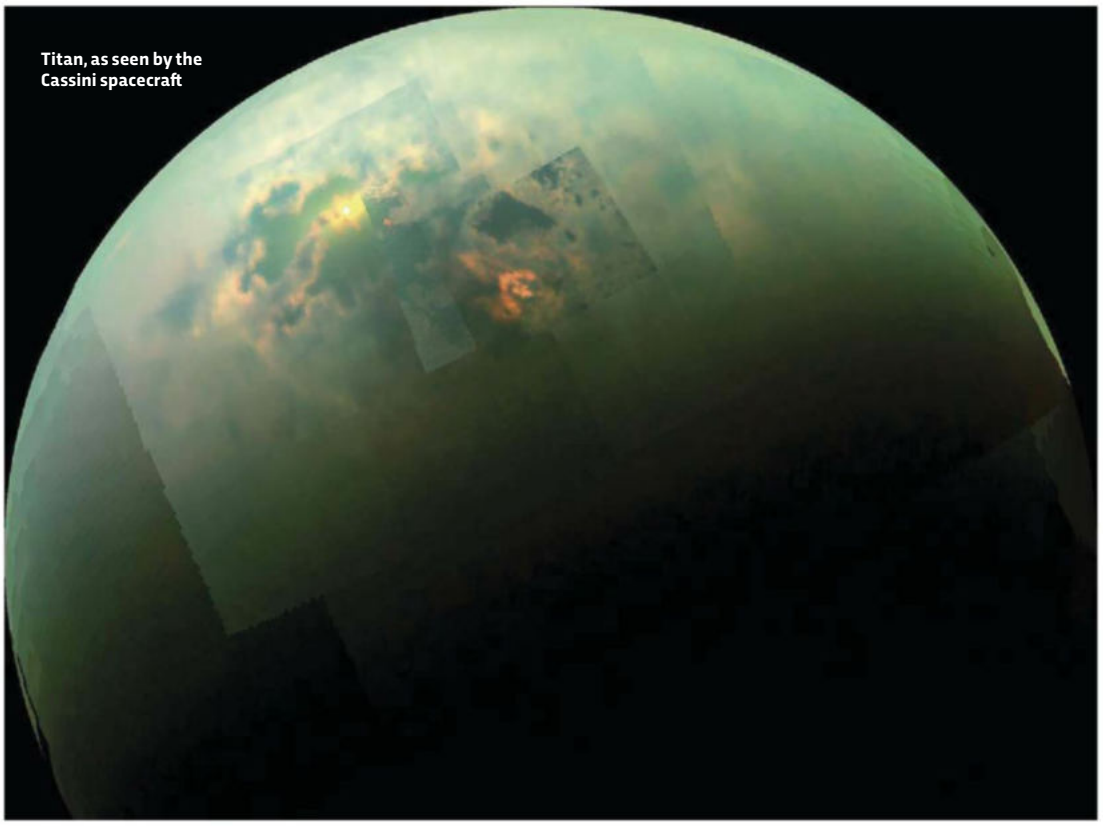
When wind blows across the moon's surface at 25km/h or more, the granules swirl into the air and start to collide. As this happens they become charged, like a balloon rubbing against your hair, and stick together. "If you grabbed piles of grains and built a sandcastle on Titan, it would perhaps stay together for weeks due to their electrostatic properties," said researcher Dr Josef Dufek.

The effect could help to explain the sandy dunes seen on Titan's surface that can reach heights of 100m, the researchers say.

To make the discovery, the team placed grains of naphthalene and biphenyl – two toxic, carbon- and hydrogen-bearing compounds believed to exist on Titan's surface – into a rotating nitrogen-filled cylinder for 20 minutes.

"All of the particles charged well, and about 2 to 5 per cent didn't come out of the tumbler," explained researcher Méndez Harper. "They clung to the inside and stuck together. When we did the same experiment with sand and volcanic ash using Earth-like conditions, all of it came out. Nothing stuck."

Earth sand does pick up static electrical charge when it's moved, but the charges are small and dissipate quickly – this is why you need water to keep the sand together when you are building a sandcastle at the seaside.



Titan, as seen by the Cassini spacecraft

IN NUMBERS

800
MILLION TONS

The weight of insects and other prey eaten by the world's spiders every year, that's twice the amount of meat and fish eaten by humans.

10
MINUTES

The length of time that brain activity can continue after death, according to researchers from the University of Western Ontario. Further study is needed to determine what is happening, they say.

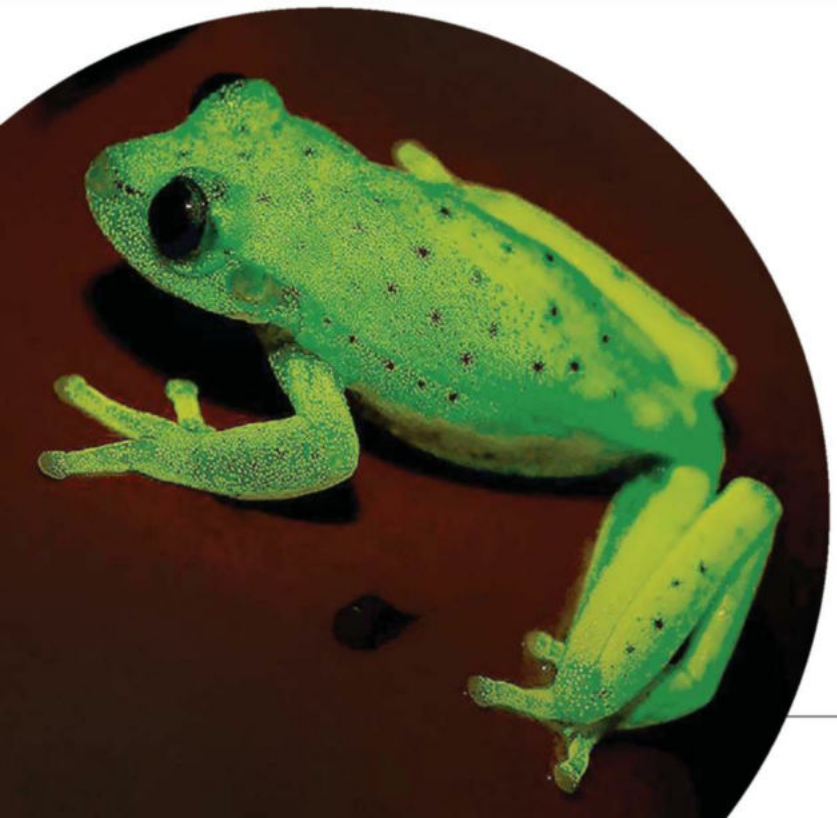
215
MILLION GIGABYTES

The amount of data that could be stored on a single gram of DNA, according to researchers in New York. That's enough to fill a tower of DVDs piled 55km high.

It turns out the South American tree frog glows under UV light. Its poi skills are still to be determined...

ZOOLOGY

WORLD'S FIRST FLUORESCENT FROG DISCOVERED IN ARGENTINA



In regular light, the common South American tree frog doesn't look like anything particularly special: it's just a small pale green animal with a pattern of red spots dotted across its back. But put it in a UV spotlight and it turns into an amphibian disco ball, with fluorescent light beaming from its body.

The unusual property was discovered by accident by researchers from Buenos Aires, Argentina while they were studying other properties of the frog's colouring.

Natural fluorescence has been observed in several species of fish and turtles, but never before in an amphibian. The psychedelic glow-in-the-dark effect occurs when shortwave light is absorbed and then re-emitted at longer wavelengths, and is caused by compounds called hyloins found in the animal's lymph and skin glands. It increases the frog's brightness by around 20 per cent during a full moon, and around 30 per cent during twilight.

The fluorescence occurs at a frequency of light that directly matches the sensitivity of the frogs' night vision, making it likely that they can see the glow, the researchers say.

FORENSICS

FORENSIC ANALYSIS OF HAIR STRANDS CAN GIVE CLUES ABOUT CRIMINALS' APPEARANCE AND LIFESTYLE

Your hair stores more information about you than you might imagine

Attention wannabe supervillains! If you want to stay one step ahead of the law you might want shave off all your hair, because researchers at West Virginia University have developed a hair analysis technique that could provide investigators with vital clues about a person's age, sex, body mass, diet and exercise habits.

"Who you are, where you've been, what you eat, what drugs you take – it all shows up in your hair," said researcher Glen P Jackson. "Depending on the question being asked, the chemical analysis of human hair can provide amazing insights into the life and lifestyle of a person."

Forensic hair analysis was once a common feature of criminal investigations, but as it relied on a simple examination of hair colour, thickness and curvature, it was often inaccurate and unreliable. Currently, DNA testing is forensic investigators' go-to technique. However, Jackson argues that hair strands found at most crime scenes don't contain enough viable DNA for analysis, and even if they do the technique can only provide a genetic profile of a suspect and nothing about their lifestyle.

"You could have genetically identical twins, and if one is obese and one is lean, we potentially could tell the difference between their hairs with our method," Jackson says.

The technique developed by Jackson's team works by analysing the differing atomic structures of the 21 chemicals that make up keratin, the protein found in hair. In a pair of recent experiments, the team used the method to identify the body mass index of subjects with 80 per cent accuracy, and their sex with 90 per cent accuracy.

PHOTOS: SANTIAGO RON/FLICKR, GETTY, JULIÁN FAIVOVICH/CARLOS TABOADA/MUSEO ARGENTINO DE CIENCIAS NATURALES/BERNARDINO RIVADAVIA CONICET

THE DOWNLOAD

TAGUA PALMS

What's that, a high-end Caribbean resort?
Nope. It's a type of South American palm tree that just might help to save the world's elephants from extinction.

How so?
The trees have large seeds measuring up to 8cm across that can be dried out, hardened and then carved into trinkets and jewellery. When polished, the resulting attractive, off-white substance closely resembles elephant tusk – so much so that the seeds have been dubbed 'vegetable ivory'.

That sounds great. But exactly how threatened are elephants?
The number of elephants in the wild is still falling dramatically. It's estimated that up to 100 animals are killed by poachers each day to meet the continuing demand for ivory.

But isn't the trade in ivory illegal now?
Well, the worldwide sale of new ivory was outlawed in 1989 – but criminal gangs continue to poach elephants and trade ivory on the black market.

Tagua seeds could offer an eco-friendly alternative to ivory

This visualisation shows material spewing from a black hole

ASTRONOMY

STARS SEEN FORMING IN WINDS FROM SUPERMASSIVE BLACK HOLE

It's a flying cosmic crèche: a clutch of newly-formed stars has been observed hurtling away from a supermassive black hole.

The stars were spotted in IRAS F23128-5919, a pair of colliding galaxies around 600 million light-years from Earth, by a group of researchers using the Very Large Telescope at the European Southern Observatory in Paranal, Chile. The team detected the young stars by looking for the distinctive pattern of radiation they emit.

The stars are thought to be just a few million years old, and are travelling away from the centre of the galaxy at high speed. It is the first time stars have been observed forming in this kind of extreme environment.

Supermassive black holes lurk in the cores of most galaxies. When they gobble up matter, they also heat the surrounding gas and expel it from the host galaxy in powerful, dense winds.

"IT IS THE FIRSTTIME STARS HAVE BEEN OBSERVED FORMING IN THIS KIND OF EXTREME ENVIRONMENT"

"Astronomers have thought for a while that conditions within these outflows could be right for star formation, but no one has seen it actually happening as it's a very difficult observation," said research lead Roberto Maiolino. "Our results are exciting because they show unambiguously that stars are being created inside these outflows."

The discovery could improve our understanding of how galaxies obtain their shapes, and how heavy elements make their way into intergalactic space. "If star formation is really occurring in most galactic outflows, as some theories predict, then this would provide a completely new scenario for our understanding of galaxy evolution," explained Maiolino.

SPACE TRAVEL

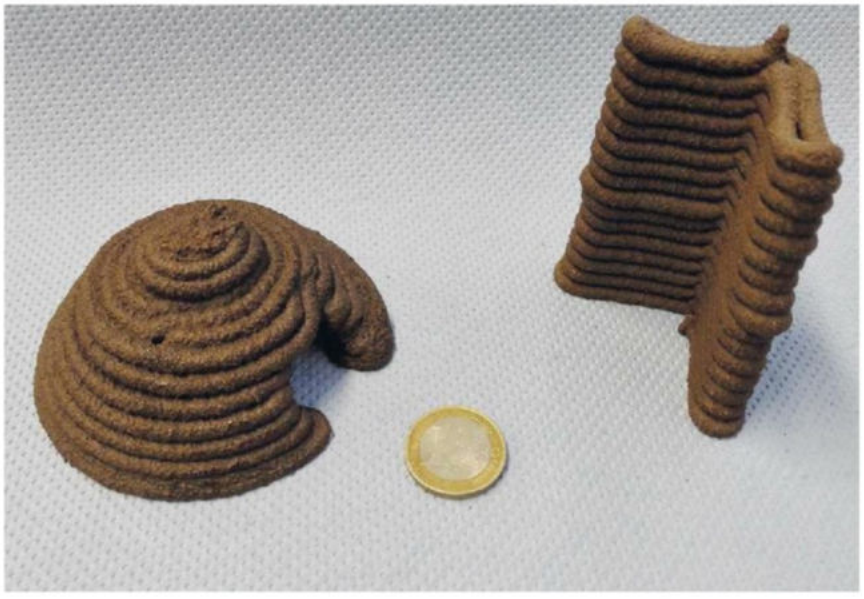
SOLID STRUCTURES 3D-PRINTED FROM 'MARTIAN SOIL'

They may look like something you wouldn't want to tread in, but these 3D-printed structures could one day help us to build a colony on Mars.

The miniature igloo and corner wall were manufactured by a team of researchers at the European Space Agency, who were investigating the feasibility of one day using locally sourced materials for building on Mars and other planets. The structures were produced by mixing JSC-Mars-1A – volcanic soil that has undergone careful processing to match the known composition and characteristics of Martian soil – with phosphoric acid, then squeezing it through a nozzle and depositing it in successive layers.

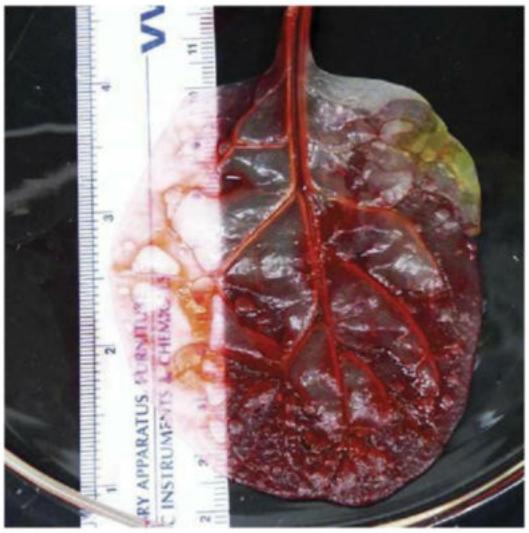
"The hardened results demonstrate the technique has potential for hardware and structural manufacturing on a variety of planetary bodies – it does not depend on the destination," said researcher Christoph Buchner.

The 3D-printed test objects represent the types of structures that Mars colonists would need to build to survive, and mark an exciting step forwards for what the researchers call 'in-situ resource utilisation' – the concept of using locally sourced materials as much as possible on planetary missions, in an effort to minimise the spacecraft's payload on launch.



These tiny objects are proof that 3D printing with modified Martian soil is feasible

PHOTOS: ESO, FOTEC/ESA, WORCESTER POLYTECHNIC INSTITUTE



Don't wear your heart on your sleeve – wear it in a salad instead

MEDICINE

HEART TISSUE GROWN ON SPINACH LEAVES

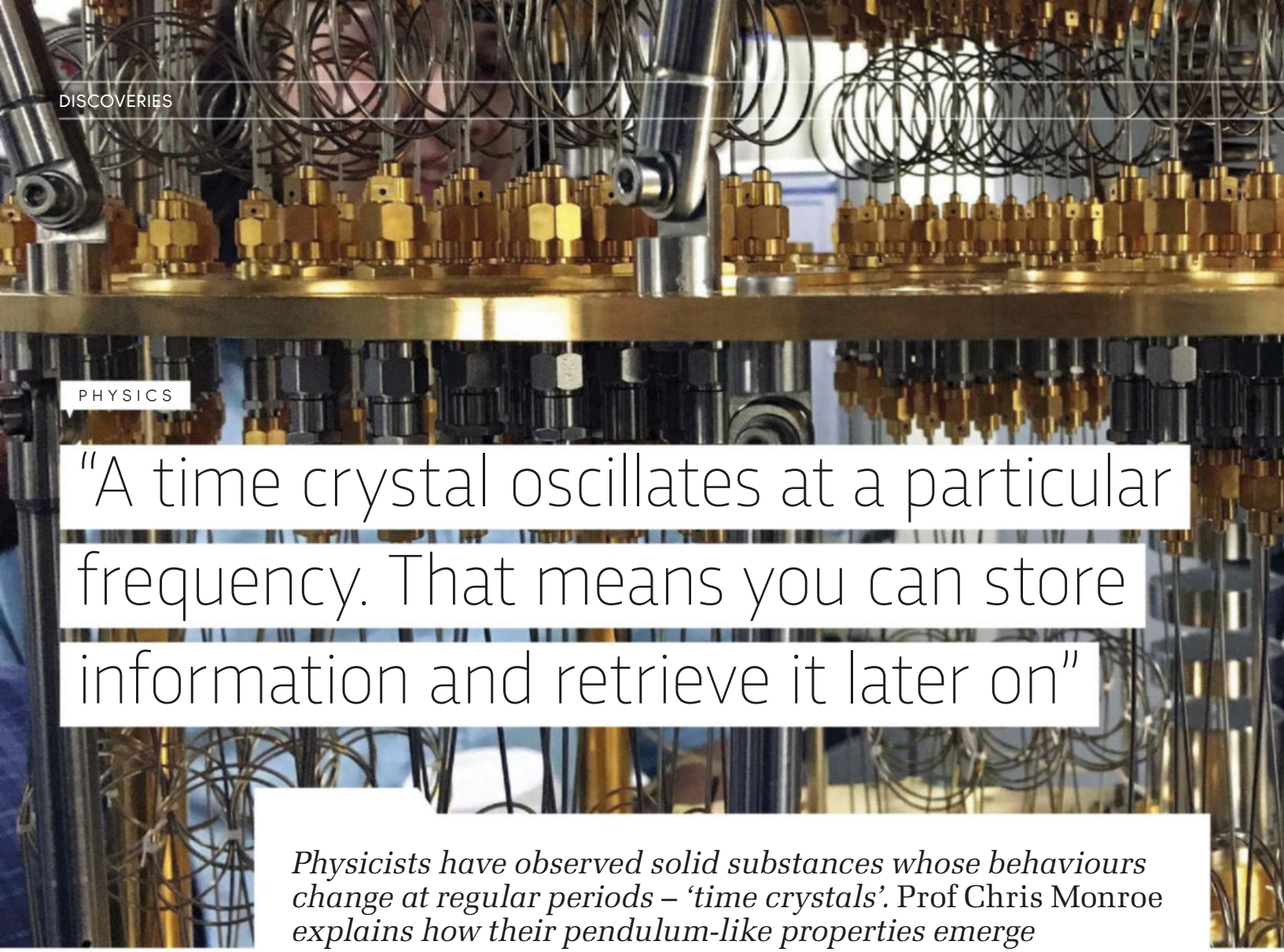
This takes growing your own to a new level: researchers in the US have created beating human heart cells using spinach leaves. The technique could eventually allow researchers to use spinach leaves to grow layers of healthy cardiac muscle to treat heart attack patients.

"We have a lot more work to do, but so far this is very promising," said study co-author Glenn Gaudette. "Adapting abundant plants that farmers have been cultivating for thousands of years for use in tissue engineering could solve a host of problems limiting the field."

The team removed the plant cells from spinach leaves by flowing a detergent solution through the veins, leaving behind a framework made mostly of cellulose. They then pumped fluids and microbeads similar in size to human blood cells through the spinach veins, and seeded them with the human cells found in blood vessels.

"I'd done decellularisation work on human hearts before, and when I looked at the spinach leaf its stem reminded me of an aorta," said study co-author Joshua Gershlak. "We weren't sure it would work, but it turned out to be pretty easy and replicable. It's working in many other plants."

The researchers are now working on refining the technique and using it to create more complex structures.



PHYSICS

"A time crystal oscillates at a particular frequency. That means you can store information and retrieve it later on"

Physicists have observed solid substances whose behaviours change at regular periods – 'time crystals'. Prof Chris Monroe *explains how their pendulum-like properties emerge*

What's a 'time crystal'?

The most straightforward comparison is to a spatial crystal – a very orderly arrangement of atoms in a lattice, like salt or diamond. There are preferred places where atoms can locate: if I know a carbon atom in diamond is here, I know at a certain distance away, in any of the three dimensions, I'll find another carbon. We say in physics that a spatial crystal 'breaks spatial symmetry'.

With time crystals, it was [US theoretical physicist] Frank Wilczek who first thought: "Why can't we have systems that break time symmetry?" This would look like a system that sort of 'pulsates' regularly in time. The pulsating is very stable. It's rigid, sort of like a spatial crystal.

RIGHT: **Ytterbium, a rare earth element or 'lathanide', is found in the minerals monazite, euxenite and xenotime**

So what's a crystal's 'pulse'?

It depends on what you're measuring. In our experiment, it has to do with the direction of magnetism [in atoms of the element ytterbium]. Think of individual bar magnets going 'North up' then 'North down', pulsating back and forth at a particular rate

How did you detect the pulses?

We observe this time crystal behaviour in a bunch of individual atoms – each a tiny, quantum bar magnet. We rotate the magnetism of each atom with laser beams. There are three beams: the first allows us to push the system, the second gives rise to interaction between magnets, and the third

PHOTOS: SCIENCE PHOTO LIBRARY X2. ILLUSTRATION: DAN BRIGHT

ABOVE: **Time crystals could be useful for building quantum computers from materials with a less orderly structure**

laser adds disorder to the system that keeps the system from heating up indefinitely. When we measure it, we get this stable pulsation.

It's like when you get an MRI [magnetic resonance imaging] scan at the hospital – that's actually measuring the magnetisation of water molecules in your brain. We measure the direction of magnetisation of each atom, and show that it oscillates up and down at a stable frequency that defines the time crystal.

Why might time crystals be useful?

A time crystal oscillates at a particular frequency. That means you can store information and retrieve it later on. Think of it this way: a clock is something you have faith will be stable, so you can look at it hours later and tell exactly what time it is by counting how many times it oscillates.

Time crystals are not particularly useful in small quantum computers with a 'clean' – that is, very orderly – lattice structure, but if you're going to build a quantum computer out of a material that's already 'dirty', such as diamond or silicon, their incredible stability could be useful. I think our ytterbium system could help us understand the physics of how a dirtier system might operate.

YOGIS

Could downward dogs defeat depression? A study at Boston University has found that attending yoga sessions twice a week can produce a significant decrease in symptoms in people suffering from major depressive disorder.

TEA DRINKERS

Put the kettle on! Tea drinking can reduce the risk of cognitive impairment by up to 50 per cent in the over-55s, researchers at the National University of Singapore have found.

GOOD MONTH

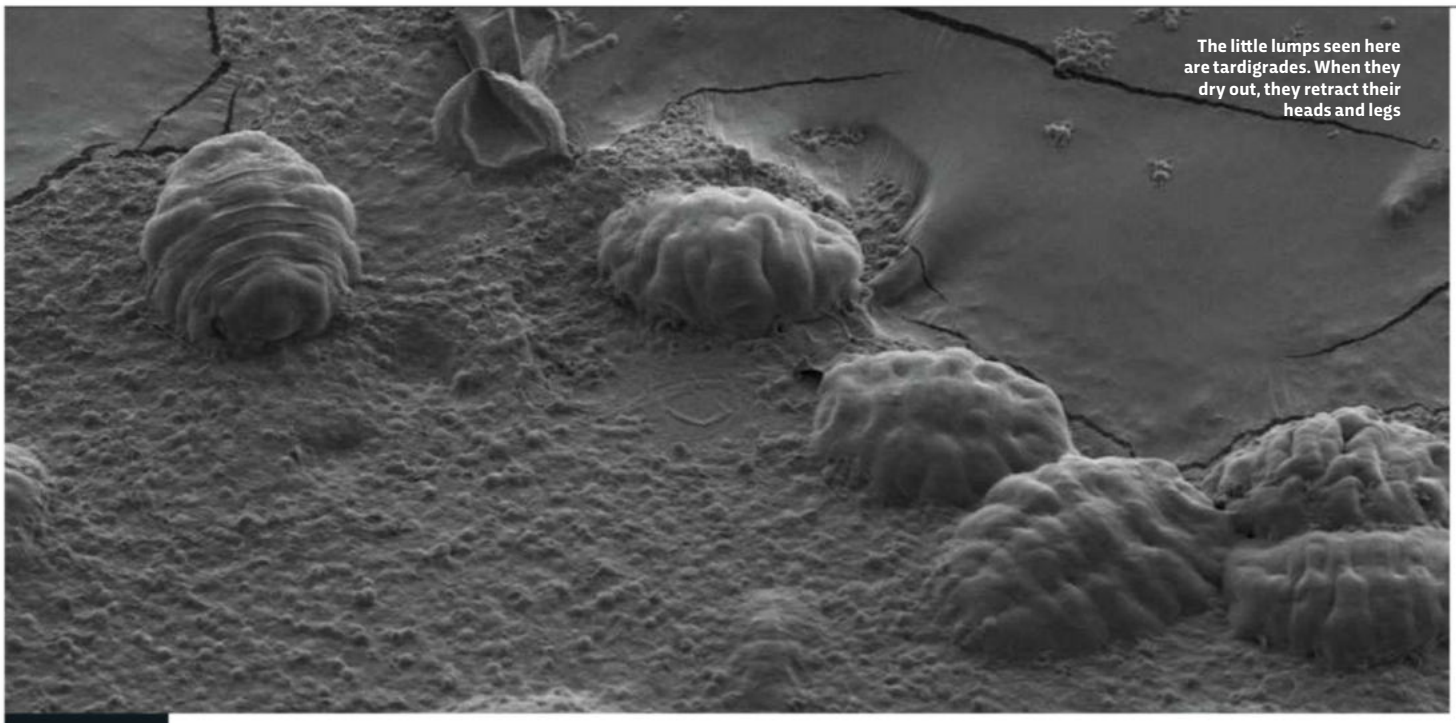
BAD MONTH

THE EASY-ON-THE-EYE

Being a bit of a looker may mean you are doomed to have short relationships. A team at Harvard University has found that those rated as attractive during high school tend to have shorter marriages and a higher rate of divorce.

POKER PLAYERS

Time for card sharps to fold their final hand? A team at the University of Alberta has created the first AI that can beat human players at heads-up, no-limit Texas hold 'em. Dubbed 'DeepStack', the bot is able to play using 'intuition', they say.



The little lumps seen here are tardigrades. When they dry out, they retract their heads and legs

BIOLOGY

WATER BEARS SURVIVE DEHYDRATION BY TURNING INTO GLASS

When it comes to survival, Bear Grylls has nothing on tardigrades. These microscopically small critters, sometimes known as water bears, can survive in environments with temperatures as high as 100°C and as low as -200°C and pressures up to six times higher than at the bottom of the ocean. They can even withstand the vacuum of space.

Now, researchers at the University of North Carolina have figured out the secret behind another of their incredible abilities – the capacity to survive for more than a decade without water.

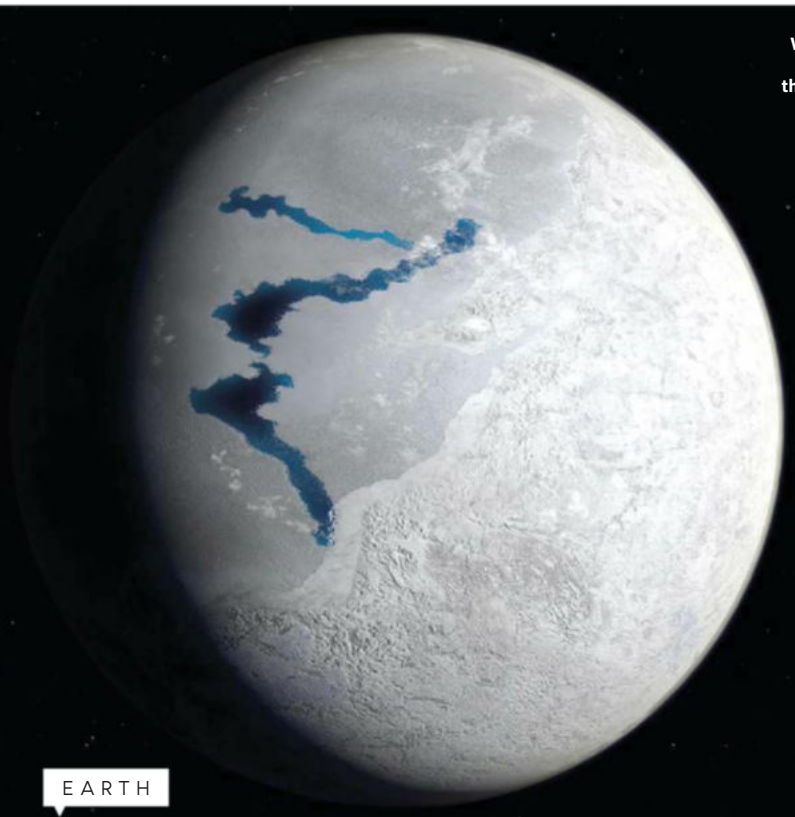
It seems that when water bears are dehydrated, the cytoplasm in their cells turns into glass, locking biological molecules in place to prevent them from becoming altered or damaged. And it all happens thanks to the action of a class of chemicals dubbed 'tardigrade-specific intrinsically disordered proteins' (TDPs).

By analysing the gene expression of three species of tardigrade under different conditions – unstressed, drying out and frozen – the team found unusually high levels of TDP gene expression during the drying-out period. "The big takeaway from our study is that tardigrades have evolved unique genes that allow them to survive drying out," said research lead Thomas Boothby.

To verify their results, the researchers put the genes encoding them into yeast and bacteria, and found the genes were able to protect these other organisms when deprived of water too. The results show that TDPs have a number of potential uses, including protecting crops from drought and safeguarding medications that normally require cold storage, the researchers say.

"Being able to stabilise sensitive pharmaceuticals in a dry state is very important to me personally," Boothby said. "I grew up in Africa, where lack of refrigeration in remote areas is a huge problem. These real-world applications are one of the things that led me to study tardigrades."

PHOTOS: T C BOOTHBY, NASA, SCIENCE PHOTO LIBRARY ILLUSTRATION: DANIEL BRIGHT



Visualisation of the snowball Earth that existed millions of years ago

EARTH

WAS 'SNOWBALL EARTH' CAUSED BY A PERFECT STORM OF FIRE AND ICE?

If you were to hop in a time machine and travel back about 717 million years, you'd be greeted with scenes reminiscent of the ice planet Hoth. But exactly how the Earth came to resemble a giant snowball has long been up for debate.

Now, a team from Harvard University thinks that the runaway glaciation event that froze the entire surface of the planet could have been triggered by a huge volcanic eruption that devastated an area stretching from present-day Alaska to Greenland and happened to coincide with several other specific atmospheric conditions.

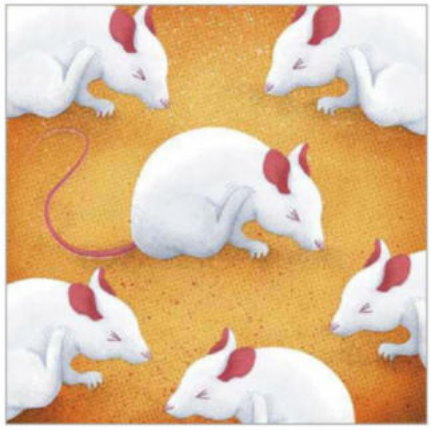
"It is not unique to have large volcanic provinces erupting," said researcher Robin Wordsworth. "These types of eruptions have happened over and over again throughout geological time but they're not always associated with cooling events. So, the question is, what made this event different?"

The team's computer models show that large amounts of sulphur dioxide could have been pushed into the atmosphere as the volcanic rocks erupted through the sulphur-rich sediment. As sulphur dioxide is highly reflective, this would've created an umbrella-like effect that shielded the Earth from the Sun's rays. The fact that the eruptions took place near the equator would've further exaggerated the effect, as this is where most solar radiation reaches the Earth.

Ice created by this umbrella's cooling effect would have then reflected more sunlight away from the surface, cooling the planet further. This in turn would've created more ice, reflecting more and more sunlight. Eventually a positive feedback loop would've taken over, making the runaway snowball essentially unstoppable.

"Cooling from aerosols doesn't have to freeze the whole planet; it just has to drive the ice to a critical latitude. Then the ice does the rest," said researcher Francis Macdonald.

THEY DID WHAT?!



CONTAGIOUS ITCHING TRIGGERED IN MICE

What did they do?
A team from Washington University played videos of chronically scratching mice to other mice. With a few seconds of seeing the video, the spectating mice would begin scratching too.

What did they find?
The itching behaviour is triggered by a structure in the mice's brains called the suprachiasmatic nucleus (SCN) releasing a chemical called gastrin-releasing peptide (GRP) – a key transmitter of itch signals between the skin and the spinal cord. The behaviour is an instinct that the mice have no control over, according to the researchers.

Why did they do that?
It is hoped that the findings can help the researchers to deepen our understanding of the neural circuits that control socially contagious behaviour.

WHAT WE LEARNED THIS MONTH

NORWEGIANS ARE THE HAPPIEST PEOPLE IN THE WORLD

This year's UN World Happiness Report has declared Norway as the happiest country in the world, ousting previous holder Denmark. The report takes into account factors such as income, life expectancy, freedom and trust. The UK placed 19th.

SKYSCRAPERS COULD BE BAD FOR OUR HEALTH

The swaying motion of skyscrapers caused by strong winds can trigger tiredness, low mood, difficulty concentrating and lack of motivation in occupants, researchers from the University of Bath say.

SAT-NAV USE ALTERS BRAIN ACTIVITIY

Using GPS reduces activity in the hippocampus and prefrontal cortex, brain regions involved in memory, navigation, planning and decision-making, a team at UCL has found. The effect is thought to be due to it negating the need to think of other possible routes.

NEANDERTHALS MAY HAVE USED PAINKILLERS

Remains of plants containing salicylic acid, a close relative of the active ingredient in aspirin, have been found in the dental plaque of a 48,000-year-old Neanderthal skeleton unearthed in northern Spain, by a team from the University of Adelaide.

SPACE

NASA'S CASSINI CAPTURES STUNNING PHOTOS OF SATURN'S TINY MOON

Of Saturn's 53 confirmed moons, Pan orbits the closest

PHOTO: NASA

NASA's Cassini probe has captured its first ever close-up shot of Pan, Saturn's tiny moon, revealing its odd shape that resembles a sherbet flying saucer.

The picture was taken during a flyby in March from a distance of 24,572km and will help to shed some light on the moon's shape and geology.

Pan is the innermost of Saturn's known moons. It orbits around 135,000km from the planet and is just 28km wide. It was discovered by NASA researcher Mark R Showalter in 1990 using images taken by the Voyager 2 spacecraft nine years earlier. Like Atlas, another of Saturn's moons, it has a prominent equatorial ridge giving it a distinctive flying saucer shape. It is named after Pan, a Greek forest god with the upper body of a man and the lower body of a goat.

At the end of April, Cassini will begin a series of 'dives' into the area between Saturn and its rings before plunging into the upper atmosphere and burning up like a meteor. Along the way, it will take detailed measurements of Saturn's gravity and magnetic fields, sample particles from the planet's icy rings and take more ultra-close images of the ring and clouds.

COULD A NEW BATTERY SOLVE OUR ENERGY WOES?

Tech, big and small, could at last receive a much-needed power-up

What looks set to be the top tech story of 2017 is already in – and it's still only May. Researchers in the US have made headlines worldwide by developing a radically new type of battery that charges far faster and holds way more charge than today's lithium cells. Oh yes, and it doesn't explode either. It's not just a terrific technology story, either. The team behind it is led by tech legend Prof John Goodenough of the University of Texas, Austin – the co-inventor of the original lithium-ion battery, and still doing brilliant work at the age of 94.

I first heard of the breakthrough from my son, who is clearly thrilled by the prospect of no longer having to listen to his dad banging on about the pathetic state of battery technology.

While computing power famously doubles every two years, battery performance has barely doubled in 20. That's why we're still using 21st-Century gadgetry with one eye on that battery icon, wondering if we can get to a charger before our device turns into a dead slab of metal.

This dismal state of affairs is more than simply inconvenient. If we're to make the most of renewable energy, we need ways of coping with those times when the wind drops or there's no sunshine. Batteries that store energy for the lean times is one pretty obvious solution.

Elon Musk, the billionaire boss of electric car company Tesla, certainly thinks so. He's just offered to supply 100 megawatts of battery storage to South Australia, whose reliance on renewable energy has led to blackouts in recent months.

He's already created a 20 megawatt battery 'farm' in California, and is willing to put his bucks where his batteries are, offering to do the Australia job for free if it takes longer than 100 days to get it installed and working. Yet not everyone is convinced current battery technology is up to the job. For example, one wind farm in Hawaii had three fires in its battery 'farm' within a year of opening.

"WE'RE STILL USING 21ST-CENTURY GADGETRY WITH ONE EYE ON THAT BATTERY ICON"

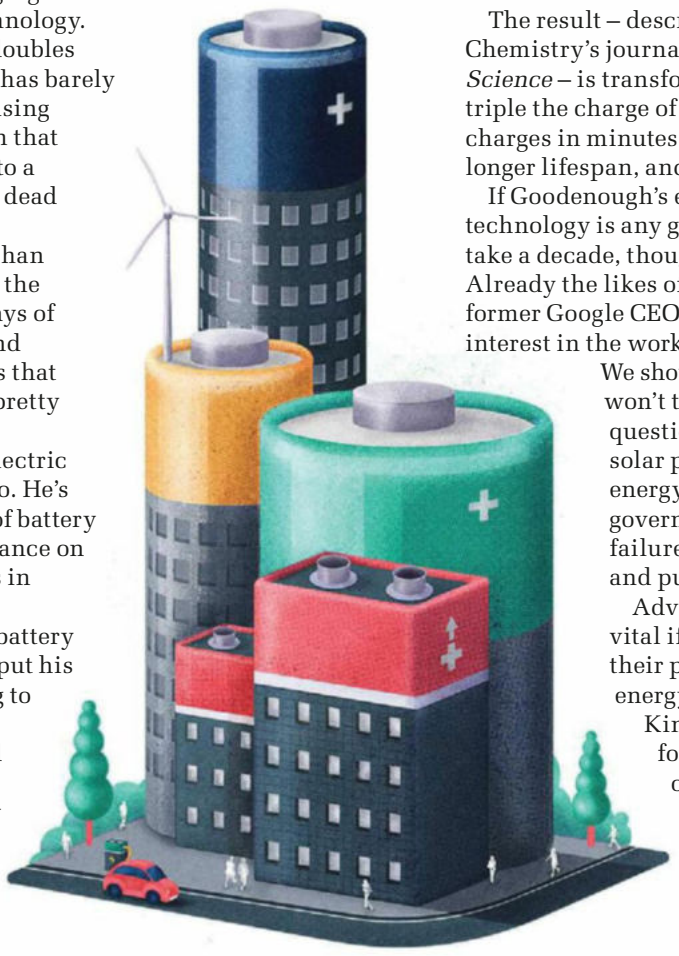


ILLUSTRATION: DANIEL BRIGHT

But now Goodenough and his team may have found the answer, by switching from lithium to sodium.

The lithium batteries that made Goodenough's reputation contain a liquid electrolyte which doesn't respond well to rapid charging. Tiny whiskers of lithium can form that affect the ability to hold charge and lead to short circuits, triggering overheating and even explosions.

One of Goodenough's colleagues, Maria Braga, decided that the answer lay in switching to solid electrolytes, which would block crystal formation. The team has now managed to get a solid glass electrolyte to work with sodium, which is similar to lithium but far more common.

The result – described in the Royal Society of Chemistry's journal *Energy & Environmental Science* – is transformational: the battery has triple the charge of its lithium equivalent, it charges in minutes rather than hours, it has a longer lifespan, and won't go off with a bang.

If Goodenough's experience with lithium-ion technology is any guide, commercialisation may take a decade, though it could happen faster. Already the likes of billionaire technologist and former Google CEO Eric Schmidt is showing interest in the work.

We should all hope commercialisation won't take long. No one seriously questions the need for wind and solar power to be part of global energy strategy. But after years of government handouts, commercial failures and now blackouts, political and public support is on the slide.

Advances in energy storage are vital if renewables are going to reach their potential. The boundless energy of Goodenough – the Li-ion King himself – may just have found the solution in the nick of time.

Robert Matthews is visiting professor in science at Aston University, Birmingham.

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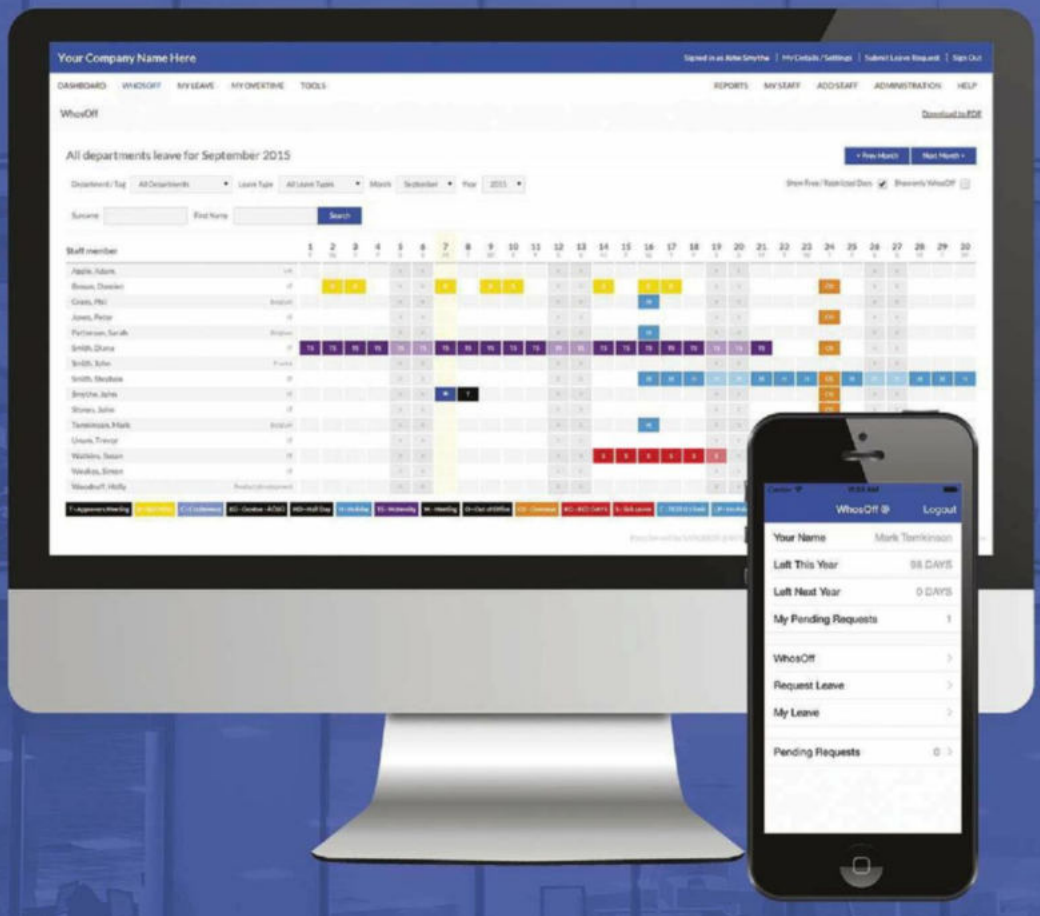

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INNOVATIONS

PREPARE YOURSELF FOR TOMORROW

MAY 2017

EDITED BY RUSSELL DEEKS

UP, UP AND AWAY

This, according to Airbus and motor vehicle design consultancy Italdesign, is the car of the future… or rather, the *flying* car of the future.

Pop.Up is a concept car design that was on display at the recent Geneva Motor Show. The vehicle features a central cockpit/passenger capsule that can be attached to different transport modules – four wheels, a quadcopter, or even a module that would let the vehicle travel through Hyperloop tubes. According to Airbus's vision, you tell the vehicle's AI where to go, and it then works out the fastest route and attaches the relevant transport modules automatically.

Airbus and Italdesign see Pop.Up working as an Uber-like on-demand service, rather than individuals buying their own vehicles. But there's plenty of time to work out the specifics: all that was on show in Geneva was a life-sized model, rather than an actual working prototype. Still, we can dream…

INTERNET

IS THE DARK WEB DISAPPEARING?

A new report suggests that the 'dark web' – that part of the internet which is heavily encrypted and provides anonymity to its users – is simply vanishing, with 85 per cent of dark websites no longer accessible.

When you visit a normal page, information is sent from point A – the server where the site is hosted – to point B, your computer. That information may bounce around numerous locations between points A and B, but is always traceable. With the dark web, heavily encrypted information is routed via many more points, so when a dark webpage is displayed on your screen, your computer does not 'know' where the data originated, and the originating server doesn't 'know' where it sent it.

Multiple dark web networks and browsers are available, but the most popular is Tor, or 'the onion router'. Originally developed by US military and intelligence agencies to protect the online communications of US agents overseas, Tor was made publicly available in 2003, but it has since been widely used for illegal activities such as identity theft and the trading of child abuse images. For this reason, 'cracking' the Tor network has become a goal of law enforcement agencies and 'white hat' hackers. The Silk Road case, where an online drugs marketplace was taken down by the FBI, became headline news in 2014. And in January, one major dark web host, Freedom Hosting 2, was taken offline by hackers.

"ONLY 4,400 DARK WEB DESTINATIONS WERE ACCESSIBLE DURING TESTING"

It seems these activities may be having an effect. OnionScan, a body which monitors dark web usage, reports that only 4,400 dark web destinations were accessible over several days of testing. This could be due to the takedown of Freedom Hosting 2, which housed many legitimate sites as well as the illegal ones. It may also be that high-profile cases such as the Silk Road – and recent allegations about the extent of spying by the CIA, NSA, GCHQ *et al* – have led to a sense of panic among those using the dark web for nefarious purposes.

While no one will be sorry to see life made harder for gun smugglers and child abusers, the dark web's apparent decline raises questions about how those with a genuine need for anonymity will be able to communicate securely online.

GADGETS

SMARTWATCHES FOR ELEPHANTS

The team discovered that African elephants only sleep for two hours a day

Question: How do you monitor the sleep patterns of wild elephants? Answer: Give them a smartwatch! And that's exactly what a team at Wits University in South Africa has done, by attaching Actiwatch fitness trackers (minus their straps) to wild elephants' trunks with electrical tape and wax.

The team, led by Prof Paul Manger, found that elephants in the wild get just two hours of sleep per day, mostly standing up (they only lie down for about an hour every three or four days). They can manage up to 48 hours without sleep, and don't seem to suffer any detrimental effects. Captive elephants, in contrast, sleep for around four hours a day. It's hoped the findings will help conservationists develop strategies that are better suited to the animals' needs, and could potentially shed more light on the mysterious nature of sleep.

Smartwatch manufacturers, meanwhile, will no doubt be delighted that a whole new market has opened up. After all, it's not like elephants had much use for reminders…

PHOTOS: GETTY X2, STAVRINIDOU ET AL

TRANSPORT

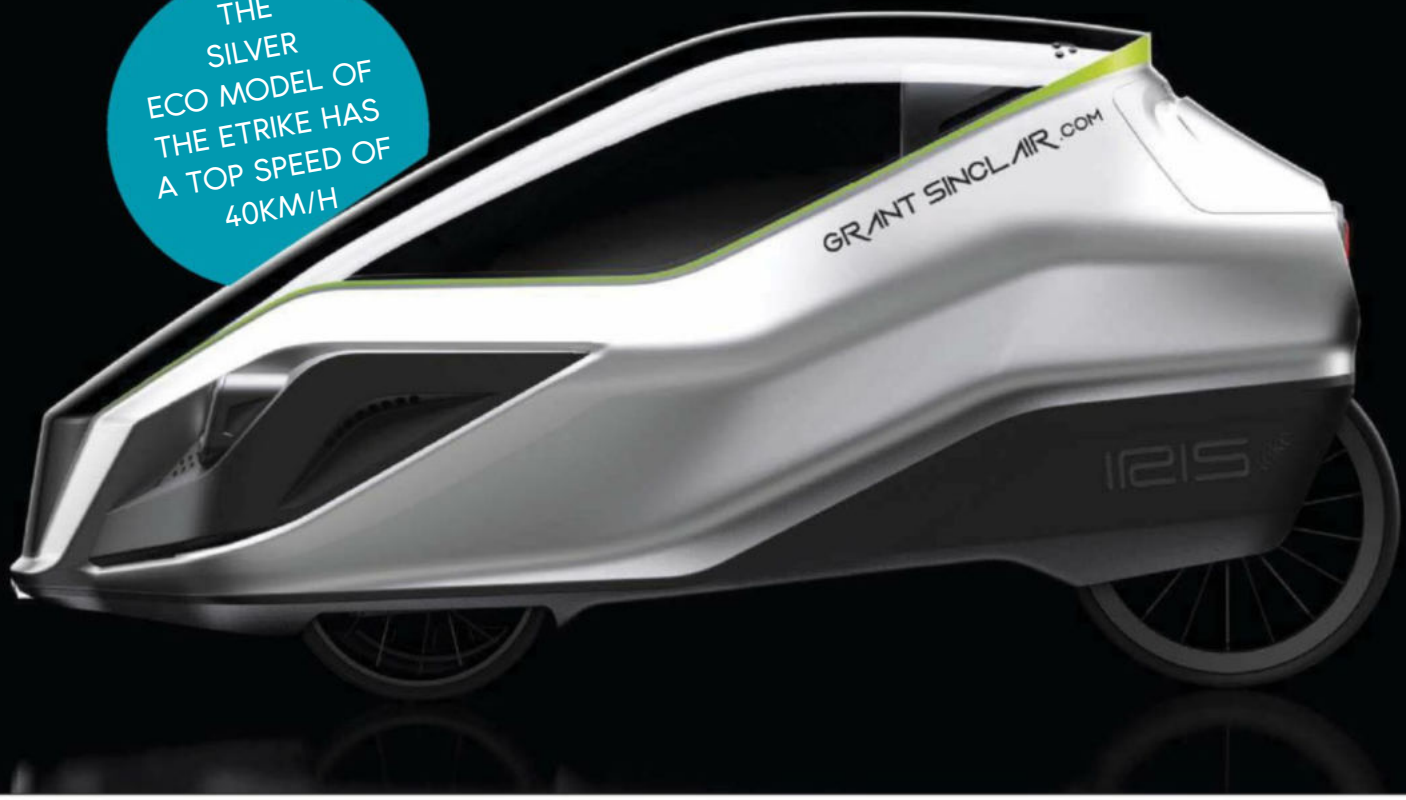
THREE WHEELS GOOD

The Sinclair C5 electric tricycle may have been a flop in the 1980s, but perhaps the idea was simply ahead of its time? That, presumably, is what Sir Clive Sinclair's nephew Grant is thinking, because he's the brains behind the IRIS eTrike, a *new* electric tricycle that's due to launch this winter.

Unlike the original C5, the eTrike features an all-over hard shell, making it suitable for use in all weathers, while inside there's an LCD dashboard and a smartphone dock. Two models of the eTrike will be available: the silver Eco model will cost £2,999 and have a top speed of 40km/h (25mph), while the £3,499 black Extreme version will have a top speed of 48km/h (30mph). Both vehicles have an 80km (50-mile) range from a single one-hour charge, and preorders (with a £99 deposit) are being taken now.

FROM TOP TO BOTTOM: **Grant Sinclair as a child in an original C5 trike; Sinclair claims that the vehicle is ideal for business use, such as medical response and food delivery; Eco model of the new IRIS eTrike**

THE SILVER ECO MODEL OF THE ETRIKE HAS A TOP SPEED OF 40KM/H



WANTED!

FROM LEFT TO RIGHT: **Computer scientist Margaret Hamilton, 'human calculator' Katherine Johnson, astronaut Sally Ride, Hubble developer Nancy Grace Roman and astronaut Mae Jemison**

EDITOR'S CHOICE

ROLE MODELS

WOMEN OF NASA

It's already possible to buy Lego sets featuring Batman, Star-Lord or Iron Man, but by the end of this year, you'll be able to pick up some superheroes of a different ilk. Five of NASA's most pioneering female scientists have been immortalised as Lego minifigures, thanks to a proposal by Maia Weinstock from *MIT News*. After her 'Women of NASA' set received 10,000 votes on the Lego Ideas website, Lego announced it would put the characters into production.

£TBC, lego.com

PHOTO: MAIA WEINSTOCK

¿HABLAS ESPAÑOL?

EMYS ROBOT

This robot head with its expressive LCD eyes will teach your children Spanish. It's aimed at kids aged between four and seven, with moving parts kept to a minimum thanks to the segmented head design. Youngsters interact with EMYS via simple voice commands, and by holding RFID-enabled tags up to the small screen in EMYS's 'chest'. To protect your child's privacy, it bucks current trends by *not* being connected to the internet. It's currently seeking funding on Kickstarter; if successful, it should start shipping early next year.

$958 (£770 approx), flashrobotics.com

BLOW YOUR OWN HORN

LUCIANO BLUETOOTH SPEAKER

Inside this ceramic, horn-shaped speaker is a Bluetooth-enabled 15W amplifier and a full-range three-inch driver, which should be enough to fill the average-sized living room. The body, meanwhile, is handmade in Nova, an Italian town that's been famous for its pottery since the 18th Century. It's available in red, blue, white, matt or gloss black, or 24K gold plate (if you're feeling flash).

From $630 (£505 approx), newblack.it

TAG YOURSELF

TAG HEUER CONNECTED MODULAR 45

The clue's in the name here! Tag Heuer's latest foray into the smartwatch market features a fully customisable design so you can choose the watch face, strap, colours and materials you like best – Tag reckons there are over 4,000 possible permutations. Then when you're bored of it, you can buy more accessories to give it an update. The Swiss-made timepiece, which runs on Android Wear, has a 1.4-inch AMOLED screen, 4GB of storage and built-in GPS, and is waterproof down to 50m.

£1,450-£4,150, tagheuer.com

RAISING THE BAR

ORBITSOUND ONE P70

The latest soundbar from Orbitsound packs a 5.25-inch subwoofer and four two-inch full-range speakers – two facing forwards, and two facing sideways. This unusual configuration fills the entire room with sound, rather than having an optimal 'sweet spot', and means you can use the speaker in whatever orientation you like. It's Bluetooth-enabled, and also boasts 3.5mm Aux and TOSLINK digital optical inputs.

£299, orbitsound.com

MASK HYSTERIA

HUSHME VOICE MASK

Do you worry that people are listening to your personal calls… or that you just don't look stupid enough while on the phone? This Hannibal Lecter-style mic-muzzle-earbud combo solves both problems. It suppresses the sound of your voice with noise-cancelling tech, while simultaneously masking it with a choice of noises (pick from birdsong, R2-D2 or rain, among others). This means that next time you take a call at your desk, you can give your work mates a giggle too.

$249 (£200 approx), gethushme.com

APP FEED

Touch Surgery

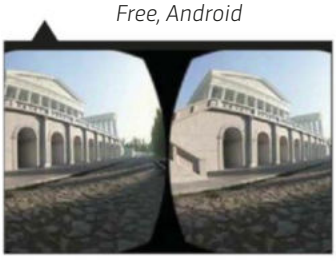
Enjoy watching TV medical dramas? You'll love this surgery simulator! It was devised as an aid for medical students, but is now available to the general public.

Free, iOS/Android

Ancient World In VR

Created by archaeologists, this virtual reality app takes you on a tour of famous ruins and monuments in Paris, Athens and Rome.

Free, Android



Steps

This app helps people who suffer from social anxiety disorder overcome their phobia by setting small, manageable daily goals and tracking their progress over time.

Free, iOS

VIRTUAL ADVENTURES

On the eve of London's first VR Show, we reveal the best ways to slip the shackles of reality, and make the most of the virtual world

RIP UP A ROBOT

There are now hundreds of VR games. Unfortunately, most of these are burdened with clunky control systems or inflict motion sickness on their users, but there have been at least two titles that have left a lasting mark: *Robo Recall* on PC and *Resident Evil 7* on PS4. The first – out this month – we played with earlier in the year. *Robot Recall* has a whiff of a story at the start but essentially your two controllers are virtually replaced by guns and you're asked to blast the bolts out of any robot in sight. Anyone's who's picked up a plastic gun at an arcade will be instantly at home, but what really impressed us was the game's speed and fluency. Every movement was mapped into the game: we could rip robots to shreds, or reach behind our backs for more weapons. It proved that, despite some clunky attempts at interfaces we've tried in the past, there's still plenty of fun to be had with the right design. Next up is *Resident Evil 7* on PS VR. The game is a claustrophobic horror set in America's Deep South. With a PS VR headset on, it's hard to say whether it's fun – sweaty might be more accurate – it's just so immersive. Every shadow becomes that little bit more suspicious, every corridor feels like an ambush and every open door a vulnerability. We could only manage half an hour at a time, but the game really shows off PS VR's power.

The robots in *Robot Recall* have rather more complexity than the storyline

A VR McLaren is probably about as close as we'll get to the real thing

TRY BEFORE YOU BUY

The motoring industry is right at the forefront of VR development. Before the technology was available to the public, companies like Jaguar Land Rover used VR headsets to sit their engineers behind the wheel before going anywhere near a workshop. Last year Jaguar even launched its electric car, the I-Pace, with a groundbreaking press conference that used virtual reality.

Now companies like McLaren and Toyota want to offer a VR experience in the showrooms, or even at home if you own a headset, by letting buyers test out their choices in the digital flesh.

We tried out McLaren's virtual showroom earlier in the year at Epic Games' offices, the company behind Unreal Engine – a 3D development tool traditionally used to create video games. It felt like a novelty at first: after all, it's pretty unlikely we'll ever really be choosing the stitching in our own McLaren 570s. However, we also saw a demo from Ikea which let customers build a virtual kitchen, followed by another one from a virtual hotel that let holiday-makers pick their room.

VR won't just be the future of how we buy cars, but how we shop in general. As 3D-scanning technology plummets in price – Google is already working on a smartphone that will be able to quickly 3D scan items and rooms – it won't be long before online shops will be able to let customers see their products virtually, and even try them out in their homes.

PHOTOS: TILTBRUSH, ROBO RECALL, AVR MCLAREN

CREATE A MASTERPIECE

Programmers, developers and filmmakers are really the only people able to work in this new virtual medium right now. But Google wants to empower everyone to create their own worlds. Their software, Tilt Brush, lets you paint in 3D, transforming the space around you into a canvas. The software works on both the HTC VIVE and the Oculus Rift. You can't paint into a void or import your own background. When it initially launched, Tilt Brush was kind of like a virtual sketchpad, letting you scribble in three dimensions. But now you can import 3D objects – whether they're scans or digital prototypes – into your paintings, allowing you to mix sketches and real objects. We can't wait to see what else they add to the medium.

HYPE UP A HOLIDAY

The city of Las Vegas has taken VR into its heart. the Las Vegas Convention and Visitors Authority has started to take the Strip's most iconic experiences and commit them to virtual film. This year at the Consumer Electronics Show (CES) we got to try it out. In a first, at least for us, we actually sat in one of the town's many restaurants, Bardot, while visiting it virtually through a Samsung Gear VR headset. Don't worry, we hadn't fallen down some post-modern dining rabbit hole – we were testing out one of many virtual tours the tourist board had built to give holiday-makers a taste of the town. We tried out one of the city's nightclubs, as well as a helicopter ride over the Strip. The most impressive VR experience, however, was the preview of a Cirque du Soleil show called *KÀ*, which had been filmed especially for the medium. You were plunged into the middle of the stage – a stage that spun, almost vertically, in the air – as the cat-like performers sprang, swung and hopped around you. The idea isn't to sell tickets, but to get ticket holders hyped about the show before they even arrive. If it's popular with its visitors, the Las Vegas Convention and Visitors Authority wants to run with the concept and roll it out across the city. And if you've been bitten by the VR bug, you'll be pleased to know that there's going to be VR theme park opening up in Vegas later this year.

GAIN PERSPECTIVE

Almost every blockbuster from the last year has come with its own whizzbang VR experience, but we think VR's transformational powers are best put to use in short documentaries. For example, ABC News created *Inside North Korea*, a 360° film which takes its audience behind the secretive state's borders. It's simple footage mostly, but because it's filmed in 360° you're able to look around the reporter's hotel room or spy on the tour guides as they keep a watchful eye on the group. The VR medium literally offers a whole new perspective.

If exploring North Korea doesn't take your fancy, then you could use the Jaunt VR platform to travel through the Hyperloop (spoiler: it's just a pipe), take a dive on a coral reef, or stroll atop one of Nepal's tallest peaks. Most exciting of all is a documentary called *First Life*, narrated by David Attenborough, which will look at how palaeontologists build a picture of what early life was like on planet Earth.

David Attenborough narrates a VR documentary

PHOTOS: ALCHEMY VR

The Missing Passenger

FREE ENTRY

The Missing Passenger is a new exhibition trail at the National Railway Museum in York by artist and director Geraldine Pilgrim. Commissioned as part of the museum's new Mystery on the Rails season, *The Missing Passenger* is just one of many activities celebrating the special place railways have in mystery and detective fiction.

The Missing Passenger runs from **23 March** to **3 September 2017**. Entry to the National Railway Museum and *The Missing Passenger* is free.

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nrm.org.uk/mystery

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THE SOUND OF UFOS [LIVE] — BRUNO SPOERRI
CARL SAGAN SCREENING AND LIVE SCORE BY EMERALD WEB
FRANK COTTRELL BOYCE. PROF: DAVID NUTT
DELIA DERBYSHIRE DAY — 80th ANNIVERSARY TRIBUTE
THE SCIENTIFIC SECRETS OF DOCTOR WHO. KNIGHTMARE LIVE
THE DARK WEB EXPLAINED BY C4'S GEOFF WHITE
CAPTAIN SCARLET 50th ANNIVERSARY EXHIBITION
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JOHN ROBERTSON PRESENTS THE DARK ROOM
THE STAR FIELD: ADVENTURES IN FLATLAND
WELCOME TO THE ZOONIVERSE WITH GRANT MILLER
DATA SAVES LIVES. FESTIVALS OF THE FUTURE
CELEBRATING WOMEN OF SCIENCE
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Your opinions on science, technology and our magazine

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MESSAGE OF THE MONTH

Night night

Further to your reply to the question about the neurological difference between sleep and anaesthesia (April, p82): anaesthetists do not, as far as I have ever heard, say to a patient "we are going to put you to sleep".

We don't like our patients to associate anaesthesia with taking Fido or Tiddles to the vet, and their beloved pet ending up in the skip. It tends to make them frightened, as one might expect.

Gary Sansom, operating department practitioner (anaesthetics and recovery)

Clearly, my bedside manner would never have been good enough to make it as a doctor! ***– Ed***

"Putting you to sleep" is something vets say, says Gary Sansom

Moonshot

With regard to your article on returning to the Moon (April, p38) my own support for manned space travel is based, at least in part, on two quotations: "Earth is the cradle of mankind, but no one stays in the cradle forever" (Konstantin Tsiolkovsky, early 20th-Century Russian space scientist) and "The Earth is now simply too small and too fragile a basket for the human race to keep all of its eggs in" (Robert A Heinlein, to which his colleague Larry Niven added, "The dinosaurs had no space programme").

While the first reason might sound a little 'theoretical', the second is surely extremely practical. Had the Chelyabinsk meteorite (for example) struck a crowded area, it could have killed dozens, or hundreds. Given a big enough impact, all human life, and perhaps all terrestrial life, could be in jeopardy.

If Earth were to be rendered uninhabitable, then evidence of our existence would continue – in orbit, on the Moon, on and around Mars, and so on. *Homo sapiens* is the first creature in the history of the Earth of whom this might be said. However, to preserve a record of the human race is not nearly as satisfying as saving the human race itself, as I am sure that many of your readers would agree!

Peter Davey, Bournemouth

Stimulating conversation

I read in your magazine about transcranial direct current stimulation (February, p34) and it said there is some evidence that this kind of brain stimulation can be used to treat dementia. The article also mentioned transcranial magnetic brain stimulation. What is the difference between these two types of brain stimulation?

Michael Landau, via email

Transcranial magnetic stimulation massages neurons indirectly with magnetic fields. This can be used to help patients with depression alongside other treatments. Direct stimulation is where a gentle current is applied to the brain via electrodes attached to the scalp. Some claim this can enhance mental performance in simple tasks. ***– Ed***

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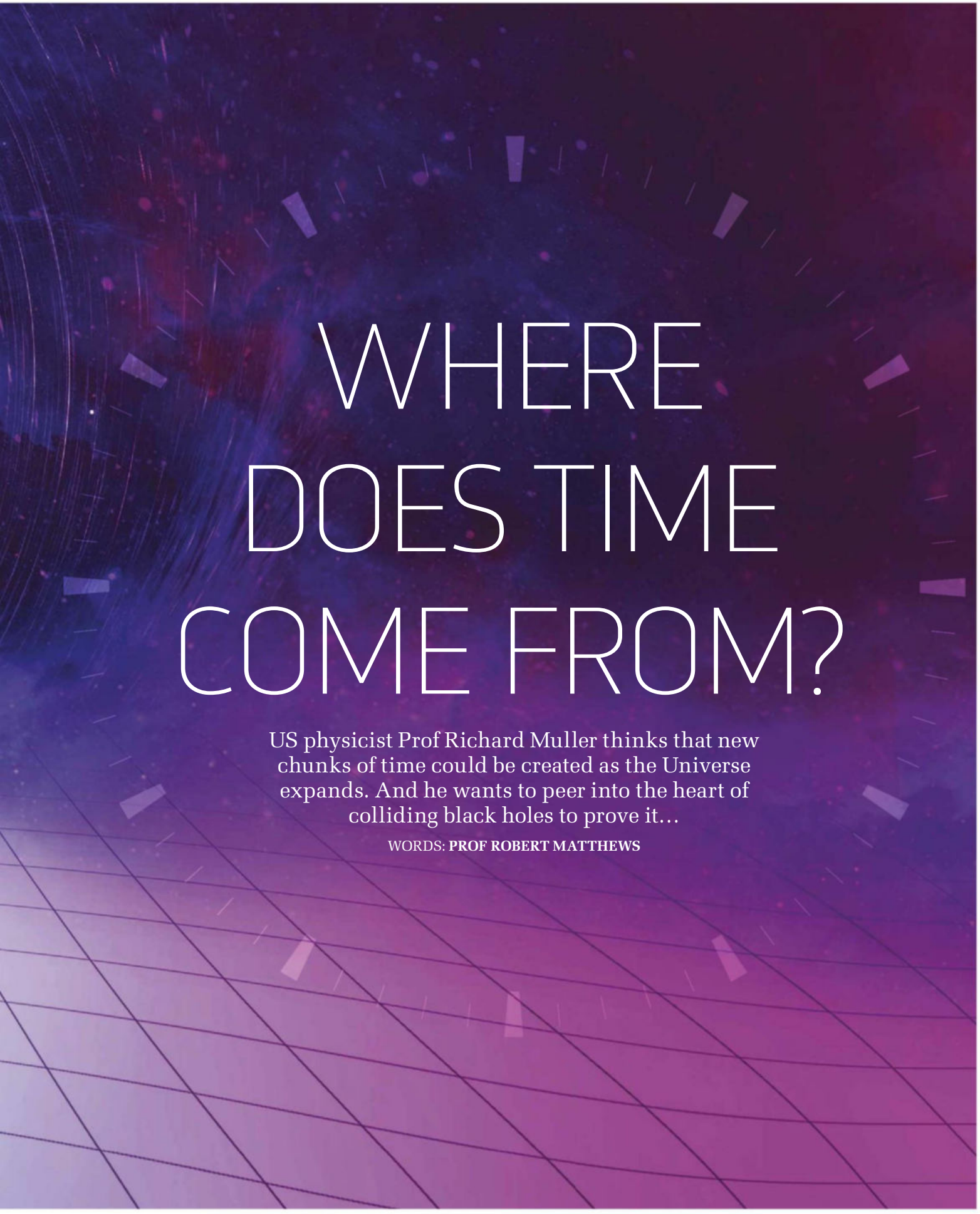


WHERE DOES TIME COME FROM?

US physicist Prof Richard Muller thinks that new chunks of time could be created as the Universe expands. And he wants to peer into the heart of colliding black holes to prove it…

WORDS: **PROF ROBERT MATTHEWS**

As science stories go, it was huge in every sense: the first-ever detection of gravitational waves, ripples in the very fabric of space and time, triggered by the collision of two black holes far beyond the Milky Way.

Gravitational waves were predicted by Einstein a century ago and picked up in September 2015 by colossal laser detectors in the United States. Now, they are being hailed as a whole new way to observe the Universe. And one physicist believes they may soon allow scientists to witness a truly mind-boggling event: the emergence of time.

According to Prof Richard Muller of the University of California, Berkeley, when black holes collide they do more than disrupt the space around them. They also create what he calls "nows": brief new instants of time.

It's an astonishing idea, but according to Muller it's no sci-fi fantasy. Within a few years, he says, the same detectors that discovered gravitational waves may provide hard evidence of instants of time being created in deep space.

RELATIVELY SPEAKING

Such claims put Muller at the forefront of research aimed at understanding this most ineffable component of our Universe. From Aristotle to Einstein, some of the most brilliant minds in history have pondered the nature of time, only to come away baffled. Around 1,500 years ago, the philosopher Augustine captured the views of many scientists, and his words continue to resonate today: "What then is time? If no one asks me, I know what it is. If I wish to explain it to him who asks, I do not know."

Muller believes recent advances in physics make it possible to cut through the confusion to reveal the truth. At present, that truth is based on Einstein's relativity. According to this, the common-sense view that we inhabit a Universe with three dimensions of space, with time flowing from past to future, is an illusion. Einstein insisted that space and time are just different aspects of one unified whole that he called 'space-time'.

While Einstein was in his twenties, he went on to show that this leads to a host of unexpected effects. Objects that zip past at close to light speed will appear distorted, and compressed in the direction of travel. Clocks moving at such speeds will appear to run slow.

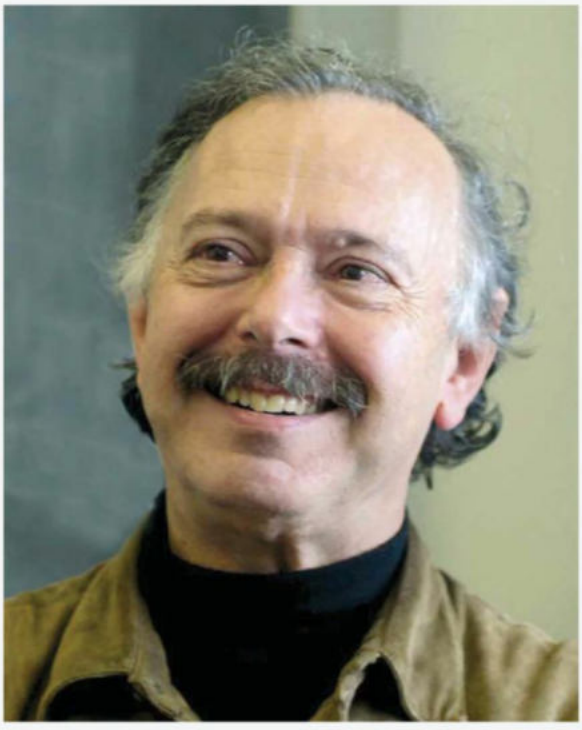
Despite their outlandishness, the predictions of relativity have all been tested – and all have proved correct. Yet there remains something odd about the supposed 'oneness' of space and time. As Muller points out, there's a simple experiment anyone can perform: "We can stand still in space – but not in time".

There are other puzzles too. The fundamental laws of nature take no account of the flow of time, giving the same answer whether time flows forwards or backwards. Yet we're surrounded by events that seem to show that time really does have an 'arrow' pointing from the past to the future, from the erosion of mountains to the decay of all living things.

> "IT OCCURRED TO ME THAT THE FLOW OF TIME WAS REALLY A GRADUAL ADDITION OF NEW MOMENTS OF TIME, NEW 'NOWS'"

Muller started pulling together all his thoughts on this, in order to write a book. He then had a flash of inspiration. "As I wrote and continued to think… it suddenly occurred to me that the flow of time was really a gradual addition of new moments of time, new 'nows'."

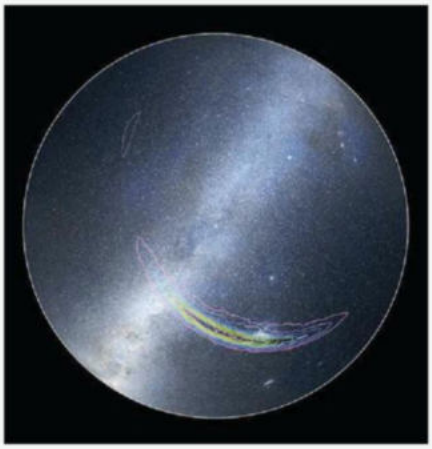
But what could possibly create packets of time? Muller found the answer in the fundamental unity of space and time. Ever since the discovery of the expansion of the Universe more than 90 years ago,



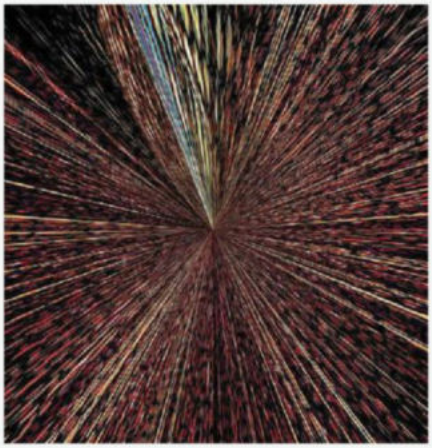
Prof Richard Muller thinks black holes could hold the secret to detecting the creation of time

One of LIGO's mirrors, which are used to detect gravitational waves

PHOTO: GETTY X2



Sky map of the southern hemisphere, revealing the location of the source of the gravitational waves detected by LIGO



Wavelet graph of two black holes merging, as detected by LIGO in 2015

PHOTOS: SCIENCE PHOTO LIBRARY X2, CALTECH/MIT/LIGO LAB

scientists have had to accept that space really can be created out of nowhere. And as space and time are just different aspects of the same thing, that means time can be created as well.

"Every moment the Universe gets a little bigger, and there is a little more time," explains Miller. That, in turn, provides a stunningly simple explanation for the supposed flow of time: "The forefront, expanding edge of time is what we refer to as now, and the flow of time is the continual creation of new nows," he says. "It all fits together."

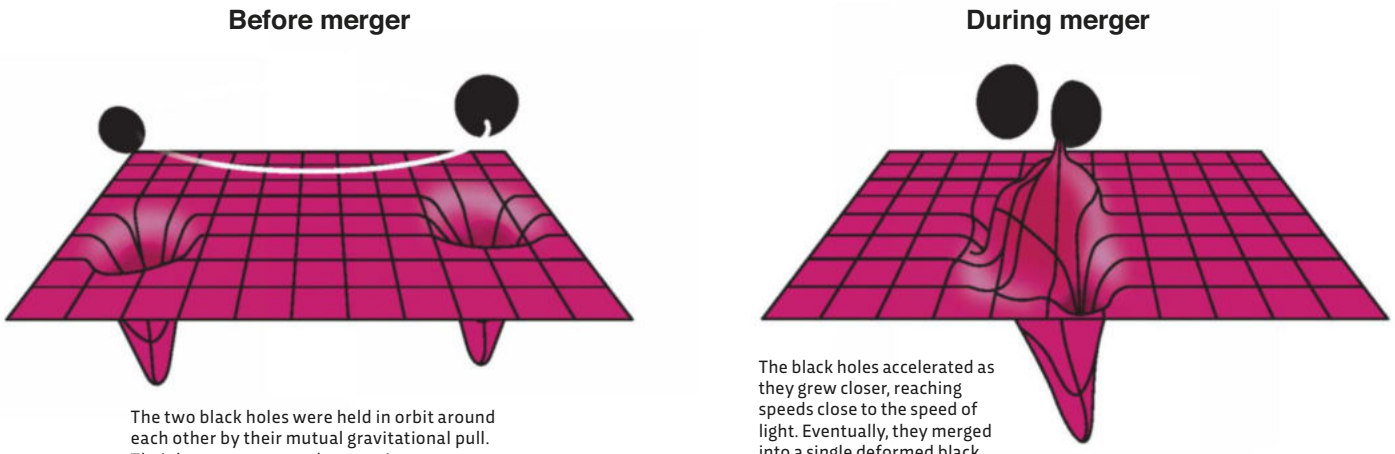
TESTING TIME

Muller wasn't content to stop there, with just an intriguing idea. He wanted to find a way of putting it to the test. And he could see no way to do it. "I had some ideas based on cosmology, but I couldn't figure out how to actually perform the tests, at least within my expected lifetime." So Muller pressed on with writing his book, which appeared last year as *Now: The Physics Of Time*.

But just as he was finishing his book, he learned of the discovery of gravitational waves by the scientists at the Laser Interferometer Gravitational-wave Observatory (LIGO). That changed everything. "When the LIGO event was reported, ▶

HOW WE'LL DETECT TIME BEING MADE

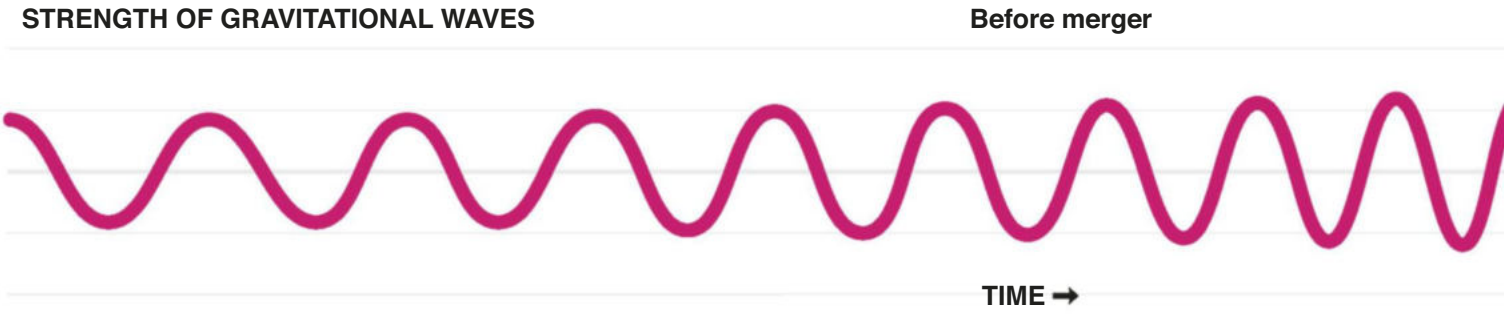
1. BLACK HOLES COLLIDE



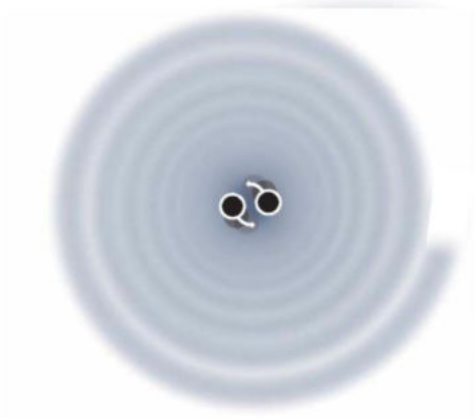
The two black holes were held in orbit around each other by their mutual gravitational pull. Their huge mass caused space-time to warp around them. Energy radiated away from them in the form of gravitational waves, leading to their orbits drawing closer.

The black holes accelerated as they grew closer, reaching speeds close to the speed of light. Eventually, they merged into a single deformed black hole that radiated enormous amounts of energy as gravitational waves.

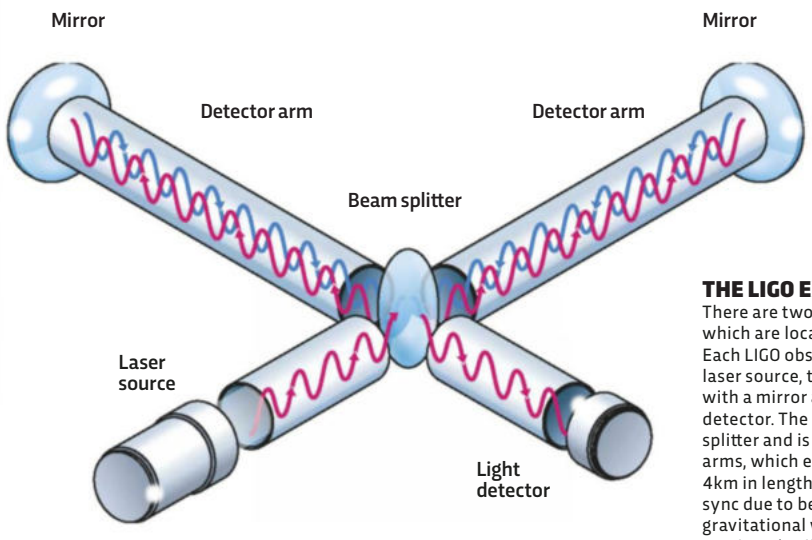
2. A SIGNAL IS CREATED



3. LIGO DETECTS IT

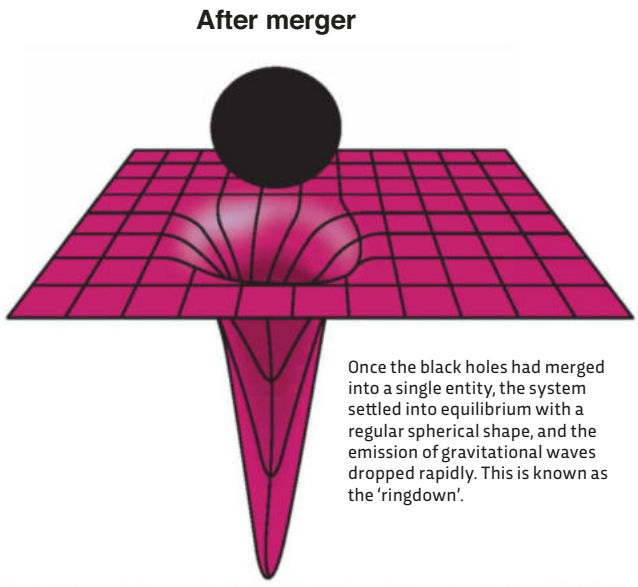


CATCHING A WAVE
Einstein's General Theory of Relativity tells us that if two massive objects, such as two black holes, are bound together by gravity, they should create ripples in the fabric of space-time. These ripples are called gravitational waves.

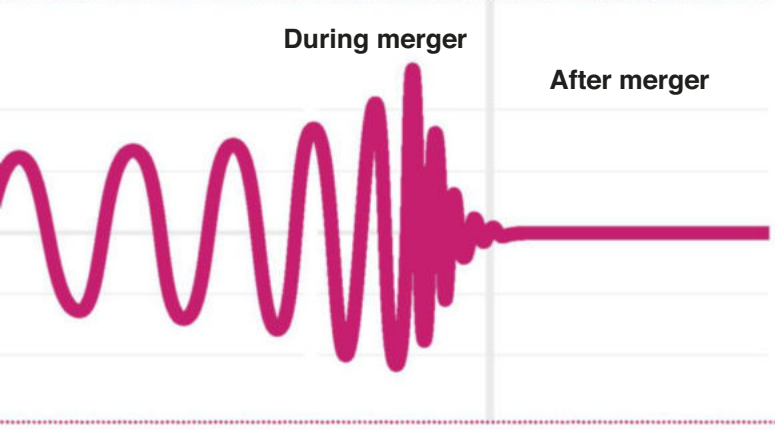


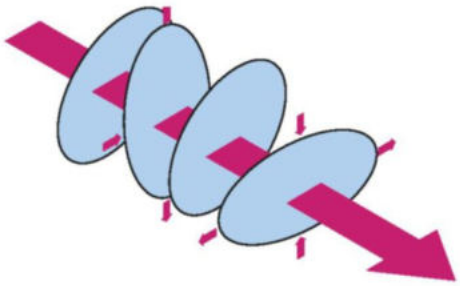
THE LIGO EXPERIMENT
There are two LIGO observatories, which are located 3,002km apart. Each LIGO observatory consists of a laser source, two detector arms, each with a mirror at the end, and a light detector. The laser shines onto a beam splitter and is sent down the detector arms, which each measure precisely 4km in length. If light waves fall out of sync due to being affected by gravitational waves, then the resulting 'spillage' of light will be picked up by the light detector.

"IF WE WITNESS THE BIRTH OF A BLACK HOLE, WE SHOULD SEE THE CREATION OF NEW TIME"



Once the black holes had merged into a single entity, the system settled into equilibrium with a regular spherical shape, and the emission of gravitational waves dropped rapidly. This is known as the 'ringdown'.





SPACE GYMNASTICS
As a wave travelling at the speed of light passes through space-time, it first stretches space in one direction and squeezes it in the perpendicular plane, then reverses the process.

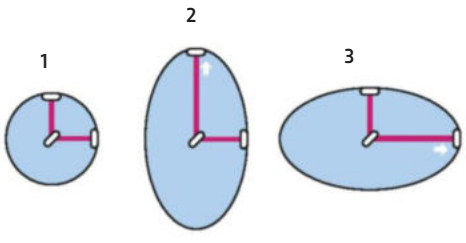


Image 1 shows the equal-sized arms when there are no gravitational waves. When gravitational waves are present, the lengths of the arms distort, as shown in images 2 and 3.

I suddenly realised that it presented an opportunity to test the theory."

Muller realised that LIGO might detect the creation of time during the collision of black holes – because in the process, they create a huge amount of new three-dimensional space.

As black holes have a reputation for destruction rather than creation, the idea that they create fresh space and time is pretty counterintuitive. To explain how it works, Muller uses an analogy for what's going on. Single black holes are often depicted as creating a huge dent in the 'fabric' of space and time. "Imagine a whirlpool," he explains. "Its total area is greater than the original area of the flat ocean, because of the way it dips." The analogy isn't perfect: "The area of water near a whirlpool is two-dimensional whereas the volume near a black hole is three dimensional," Muller points out, "But except for that, the analogy is good."

So if we could witness the birth of a black hole, we would see more than just the creation of new space, says Muller: "We should see the creation of new time." The trouble is, without knowing the precise moment the black hole is formed, there's no way to detect the delay created by the newly born chunk of time.

But Muller realised that the LIGO event of September 2015 showed there's a way around this. It was triggered by the birth of a black hole from the collision of two others spiralling in towards each other. This is an event that can be timed with split-second precision.

According to Muller, the collision would again create fresh space, as the final black hole has a mass larger than either of the originals, and thus forms a bigger depression in space-time. "I was able to do a rough calculation, and the answer is that the three-dimensional volume surrounding two such large black holes increases by millions of cubic kilometres when they combine."

Muller then estimated the amount of extra time created. The answer is small, but not hopelessly so: around a millisecond. Scientists at LIGO should be able to detect the appearance of this brief 'now'

"THE VERY FIRST LIGO EVENT WAS ALMOST STRONG ENOUGH TO TEST THE THEORY"

as a short delay in the arrival of gravitational waves that signal the merger of the two original black holes into the final behemoth.

TIME, PHYSICISTS, PLEASE!

Despite the promising results of his back-of-the envelope calculations, Muller wanted them to be re-done using the full power of Einstein's General Relativity. He got in touch with Shaun Maguire, a theoretician at the California Institute of Technology. "Shaun is a real expert in relativity theory, and together we were able to do the math with some degree of rigour," says Muller.

Maguire confirmed the original estimates, along with the idea of being able to detect the creation of brand new 'nows' using LIGO.

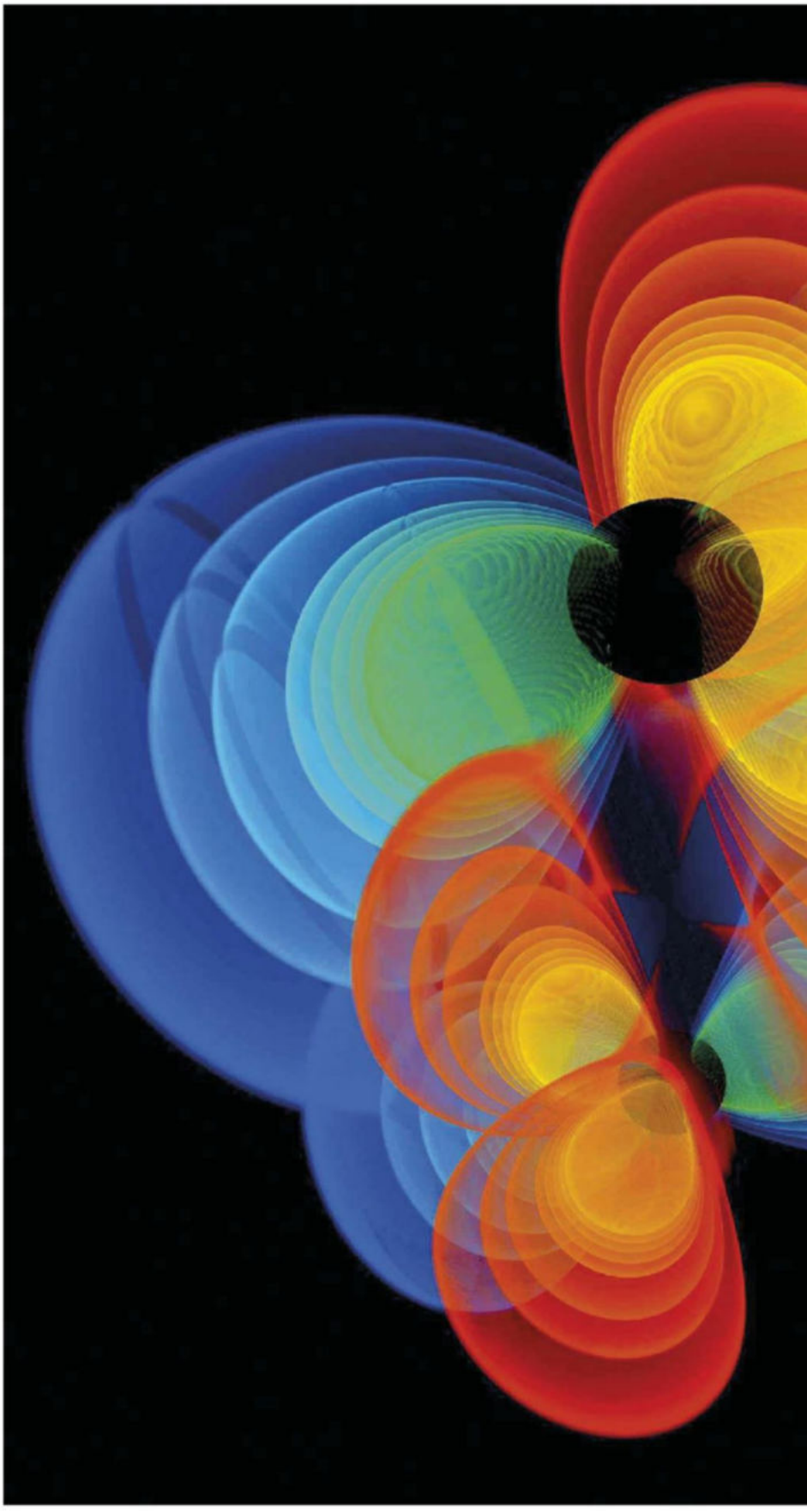
Muller hopes to put his claims to the test by the end of the decade: "The very first LIGO event was almost strong enough to test the theory," he says. "I am optimistic that we will get an even stronger event in the next year or two."

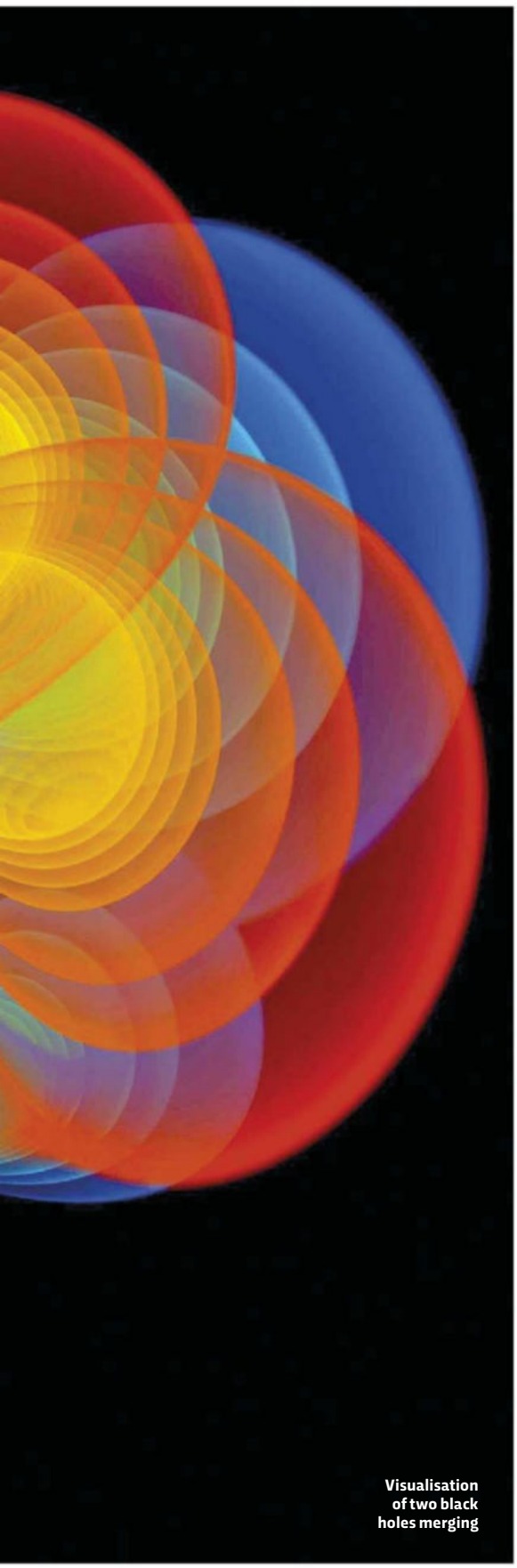
Confirmation may come even sooner, however. Muller has recently teamed up with a colleague to devise a test of his ideas in the lab. "It involves creating a microscopic amount of space locally and measuring the equally microscopic amount of time using a very sophisticated clock," says Muller. "We're not giving away the details yet because we want to be the first to do it."

So what do others make of Muller's daring new vision of time? "They are intrigued," he says. "Nobody has found a flaw yet, but until confirmed, they are withholding judgment – as am I."

Perhaps time is about to reveal its true nature in the laboratory experiments planned by Muller and his colleagues. Or perhaps fresh clues will emerge from studies of the cosmos. One thing's for sure: after millennia of speculation and theorising, if answers do emerge, it won't be before time.

Prof Robert Matthews is a science writer and visiting professor of science at Aston University, Birmingham.





Visualisation of two black holes merging

TIME TRIVIA

Muller's claim that time is created in deep space is not the only amazing theory about time...

1 According to Caltech cosmologist Dr Sean Carroll, the flow of time from past to future may be the symptom of our Universe having emerged from another universe that existed before the Big Bang and subsequently gave birth to our own.

2 In 1967, two American theorists derived an equation describing the quantum state of the whole Universe. Known as the Wheeler-DeWitt equation, it includes many key features of the cosmos, such as its size. But one aspect is absent: time. Some theorists believe this implies that time only exists in our minds.

3 According to theorist Prof Lee Smolin at the Perimeter Institute, Canada, the existence of life in the Universe is the result of the laws of physics evolving to their current state over an infinite number of previous universes. If true, this means that our very existence is proof that time does exist.

4 In 2009, physicists at the universities of Bristol and Cambridge showed that the passing of time revealed by, say, the cooling of a cup of tea, may be due to a quantum effect called 'entanglement'. This involves the particles in the tea interacting with their surroundings, being bound together and becoming harder to distinguish from each other – a one-way process that requires the forward progression of time to occur.

5 Dark energy, the mysterious anti-gravitational force that propels the expansion of the Universe, may be linked to the existence of the arrow of time. Last year, two cosmologists at the Yerevan Physics Institute showed that dark energy leads to the growth of entropy, a measure of disorder, in the Universe.

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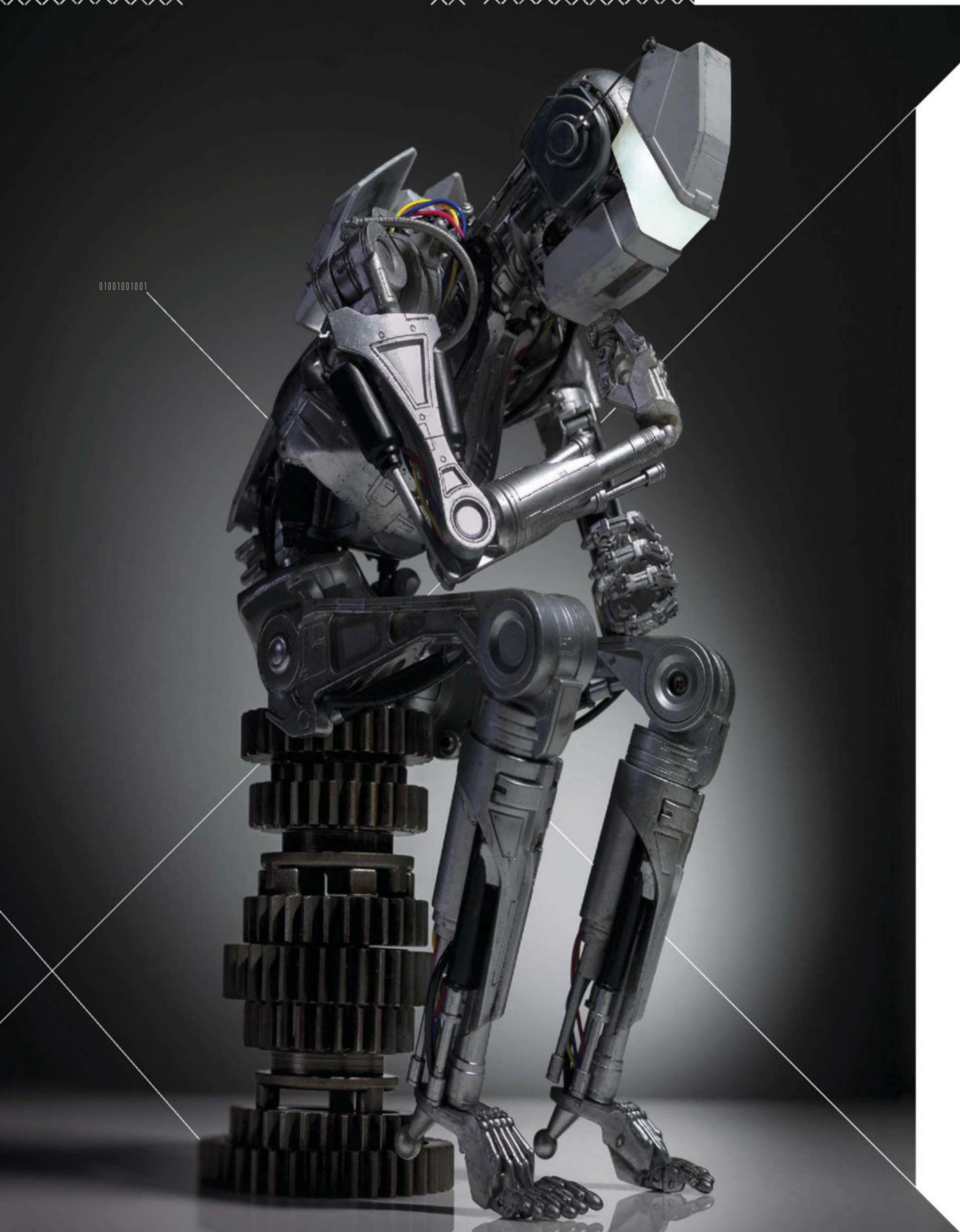
THE ROBOTS THAT CAN LEARN

ROBOTS ARE EVERYWHERE THESE DAYS, BUT HOW CLOSE ARE THEY TO THE NEXT NATURAL STEP IN THEIR EVOLUTION – THINKING FOR THEMSELVES?

WORDS: Dr Peter Bentley

ILLUSTRATION: PHIL TOLEDANO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Robots are customarily portrayed in sci-fi movies as futuristic creations that walk on two legs and think like a human. But this isn't really an accurate portrayal, as we've been using robots of one kind or another for some time – they just look a bit different. Some of the earliest programmable machines ever invented were looms made to weave fabric in the early 1800s, while robot arms have been used in our factories since the 1960s, and the military have used robotic weaponry such as cruise missiles since WWII.

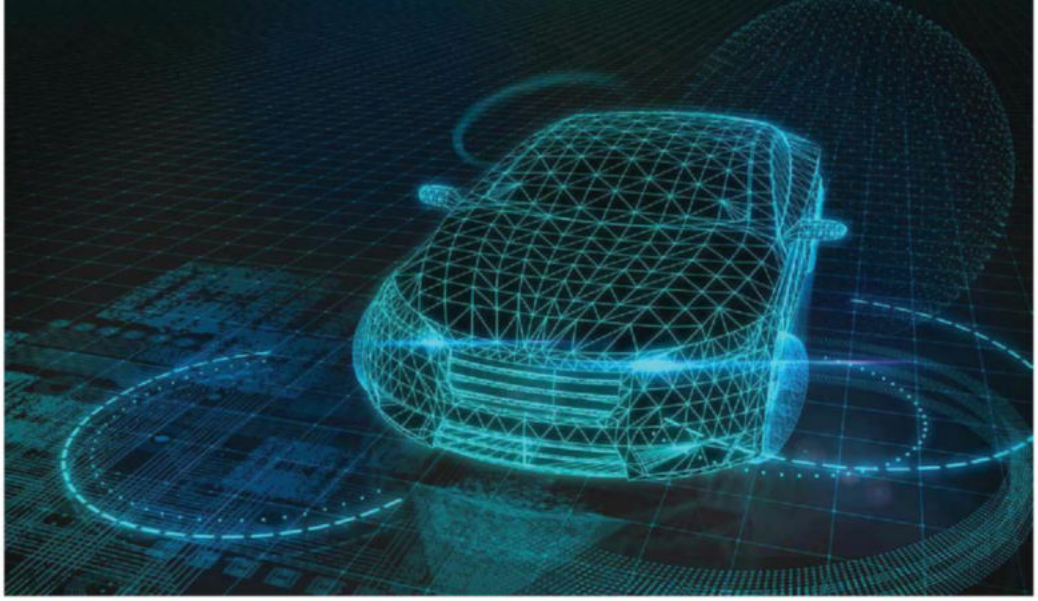
In fact, these days our everyday lives are practically overrun by robots hiding in plain sight. Our dishwasher is a robot that stands permanently in the kitchen, washing away the remnants of our meals; our vehicles are robotic devices that listen to the movement of our hands and feet, and manage the firing and transmission of a combustion engine, the movement of suspension, and the braking of wheels. Even our alarm clocks are little robots that follow a simple program to make sure we wake up at the right time. But how close are we to creating the thinking machines of science fiction?

ROBOT SEE, ROBOT DO

In the last few years, a sea change has begun to take place. Breakthroughs in artificial intelligence and 'machine learning' research are now allowing us to create devices capable of more than following a set of simple instructions – these robots are capable of learning for themselves. For example, the new generation of cars can study our driving styles and adjust how they respond to us. Some can park themselves, perform emergency braking, or drive themselves on motorways. The best digital recording devices can now anticipate or predict the kinds of programmes you might want to watch, and store them without you even asking them to.

And this is just the beginning. Take 'Paul', a portrait-drawing robot that was created by London-based artist Patrick Tresset. Paul understands what it sees by using a software simulation of the neurons used in the human brain's visual cortex – the region that processes information from our eyes. Paul finds

"OUR INTELLIGENT AUTOPILOT SYSTEM IS CAPABLE OF PERFORMING MANY PILOTING TASKS WHILE HANDLING SEVERE WEATHER CONDITIONS AND EMERGENCY SITUATIONS"



LEFT: **Patrick Tresset with Paul, the robot that can draw portraits**

ABOVE: **In the last few years, we've seen cars th can drive and park themselves**

the important features and draws what it sees, using lines of different lengths. The images that are produced have a sketch-like quality that makes them almost impossible to distinguish from something that's been drawn by a human.

"Trying to do anything that a human does with a robot makes us realise the complexity of the tasks we perform naturally without thinking," explains Tresset. "It also shows us the complexity of physical reality."

It's one thing to paint a portrait on a fixed canvas, but it's quite another to learn the skills of our most highly trained and responsible professionals. For example, could an AI ever fly a passenger plane with the same skill as a human pilot, and keep the passengers safe no matter what? Computer scientist Haitham Baomar thinks it could. His research at University College London adds an additional layer of intelligence to aircraft autopilots, enabling them to cope even when the aircraft is faced with unpredictable weather or damage.

"Our Intelligent Autopilot System is capable of performing many piloting tasks while handling severe weather conditions and emergency situations such as engine failure or fire, rejected take-off, and emergency landing, which are far beyond the current capabilities of modern autopilots," explains Baomar.

The AI uses a neural network that operates in a similar manner to the human brain, with many different neural nodes arranged in tiers and each one solving a different part of the task simultaneously. Each successive tier recieves the output from the previous tier rather than the raw input. The nodes ➤

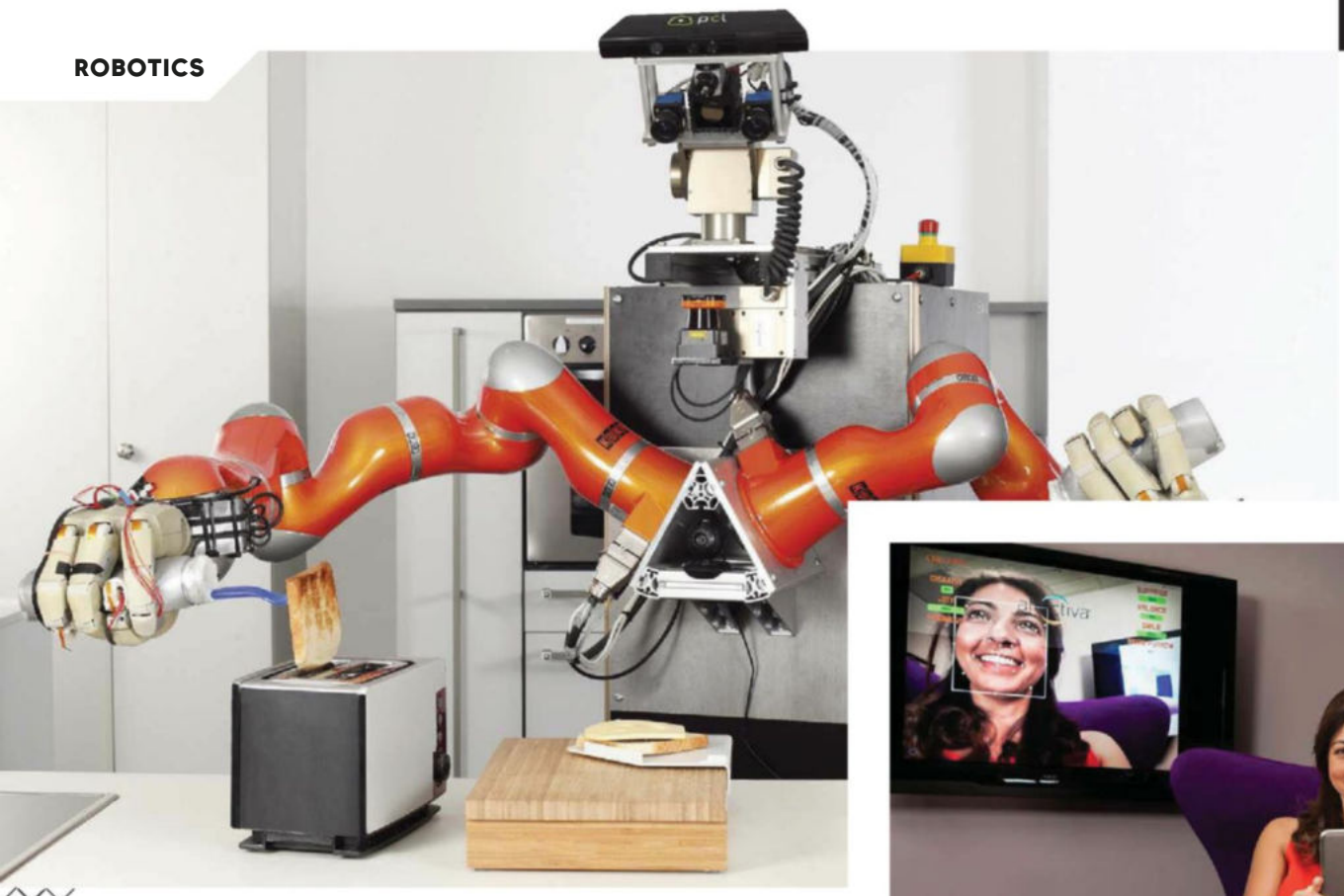
WHAT IS MACHINE LEARNING?

Machine learning is a type of artificial intelligence that focuses on enabling a computer to learn new information all by itself. Some learning methods allow computers to find patterns in large amounts of data, such as identifying similar sets of genes across a selection of DNA sequences. Others can cluster data into different groups, allowing them to find different patterns of fraud or normal behaviour in credit card transactions, for example.

Others are taught to recognise data by viewing many different examples, so they can understand text or different objects in a video. Still others learn the 'shape' of data so that they can predict what might come next, enabling them to anticipate where an object may move, or how the stock market might change.

Over many decades, all these different learning methods have grown from two main sources of inspiration: statistical mathematics and biology. Most recently, some of the biology-inspired methods such as genetic algorithms (based on natural evolution) and deep learning (inspired by the way that neurons learn in the brain), combined with some clever new maths, have produced some of the most impressive results we've seen in robotics.

PHOTOS: PHILIP EBELING, GETTY. ILLUSTRATIONS: JOE WALDRON



ABOVE: **Robot chefs could spell the end of sweating over a hot stove**

BELOW: **Dr Rana el Kaliouby demonstrates emotion-sensing technology used by her company's artificial intelligence**

each have their own bank of knowledge built up from their original programming rules, plus anything they've experienced.

Just as a human pilot may be simultaneously using one part of their brain to move muscles, one part to assess instruments and another to speak, the AI uses many separate parts of its brain to solve all the different problems of flying. The AI learns directly from observing human pilots, watching their every move in microscopic detail in order to learn how to cope with whatever gets thrown at it. It can then apply those skills to novel situations, flying new aircraft in scenarios and conditions that it has never seen previously. The system is designed to complement human pilots rather than replace them, but Baomar hopes the AI will improve air safety dramatically.

"I THINK IN THREE TO FIVE YEARS WE WILL FORGET WHAT IT WAS LIKE WHEN OUR DEVICES DIDN'T UNDERSTAND EMOTION"

IRON CHEF

Researchers at the University of Maryland have taken a similar observational approach and used it in the kitchen. Their robots can watch videos of people preparing and cooking food, and by doing so, learn to perform similar actions.

"We use neural networks to acquire knowledge for our robots by learning the functionality of objects," says Prof Yiannis Aloimonos. "Can this tool be used for scooping; can this object be used as a container? Our neural networks look at many examples and they have been taught to make geometric calculations. The combination of deep learning with geometry leads to recognition of the action being performed."

These AIs learn the underlying 'grammar' rules of action so that they can achieve their intended goal without necessarily needing to perform identical motions. For example, the rules of stirring using a spoon to repeatedly mix a liquid in a pot apply to any liquid and any pot. A simpler AI might only learn how to use one specific spoon for one specific pot, containing one specific kind of soup. This higher-level thinking using such grammar rules is then combined with a large number of processes that track and monitor the hands, the objects, tools and their movements, all continuously running in the background. "All of this implemented in a robot gives rise to the robots of the future that 'understand' the humans around them, and learn from them," explains Aloimonos.

Baomar thinks this form of robotic learning can find countless practical applications. "I believe that if we give robots the ability to learn from humans or even from other systems, the outcome should be intelligent robots that are capable of learning a wide spectrum of skills, ranging from domestic chores to performing surgery and flying complex machines," he says.

COME WITH ME IF YOU WANT TO LOVE

So the robots of the future are likely to be capable of learning and performing complex, highly skilled tasks. But how about emotions? Humans are complex creatures, unpredictable and often not entirely rational. Our emotions are just as important as our intellect in driving our actions. Affective computing – software that recognises and interprets our emotions – and human-computer interaction has started to enable AIs to detect emotions.

"We know from years of research that emotional intelligence is a crucial component of human intelligence," says Dr Rana el Kaliouby, CEO of artificial intelligence company Affectiva. "People who have a higher Emotional Quotient [EQ] lead more successful professional and personal lives, are healthier, and even live longer."

Affectiva is using deep learning, a special kind of neural network containing many layers of neurons, to enable computers to detect our emotions from our faces. Their AI is trained on a vast database of more than half a million faces analysed from people in 75 countries, with 50 million new emotion data points – a face expressing emotion such as happiness, sadness or surprise – being added every day.

"We are giving machines the ability to sense and respond to human emotion, something that is deeply human but that today's technology has not been capable of doing," says Kaliouby. "We like to say we are bringing AI to life!"

Tomorrow's robots will not be mere machines, cold and heartless. They will be emotionally aware – and it will happen soon, researchers say.

"I think in three to five years we will forget what it was like when our devices didn't understand emotion," says Kaliouby. "It's similar to how we all assume that our phones today are location-aware. Someday soon, it will be the same for emotions."

Tresset wonders what the robots that learn will be able to do in the future. "Robots can already learn, but as long as they are not able to take the decision to produce art, they cannot be seen as artists. Intentionality is very important in art," he says. "If a robot on an assembly line starts to hit a car to produce a sculpture, then will it be an artist? If a military drone starts to dance in the sky then it will it be an artist?"

"When we design intelligent robots," says Aloimono, "it is as if we are trying to understand ourselves – it is what the ancient Greeks referred to as 'gnothi seauton' ['know thyself']. This quest will never end."

Dr Peter Bentley is a computer scientist and author based at University College London.

DISCOVER MORE

Listen to *The Rise Of The Robots*, a BBC Radio 4 series exploring the role of robots in science and culture across the ages bbc.in/2kBstus

FIVE OF THE SMARTEST ROBOTS IN HISTORY

1966
ELIZA

One of the first examples of a chatterbot. When running a script dubbed DOCTOR, ELIZA could ask and answer questions like a psychotherapist. It didn't understand a great deal, but with some clever programming was still able to convince many users of its intelligence.

1994
VIRTUAL CREATURES

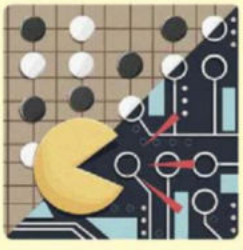
Computer artist and researcher Karl Sims created a group of virtual creatures that inhabi d their own virtual universe. Using genetic algorithms, they evolved until they could swim, crawl, jump and compete against one another. Unfortunately, they were too concerned with their own virtual lives to talk to us.

1997
DEEP BLUE

Deep Blue was catapulted into public consciousness when it won a chess game against grandmaster Garry Kasparov – the first supercomputer to achieve such a feat. However, it was given a lot of help from human programmers and used pretty basic AI methods to think of its moves, so maybe it was not so bright after all.

2011
IBM WATSON

IBM Watson was the fir AI human players at US TV quiz show *Jeopardy!*. This AI was clever enough to process text and then found likely answers to the questions asked using its internal body of knowledge, which comprised around 200 million pages of content. Sadly, it struggled to answer some basic questions.



2015
DEEP-Q NETWORK

This earlier work from the m behind AlphaGo, the AI that defeated a master of the complex Japanese strategy game *Go*, learned how to play 49 classic Atari games just by looking at the screen – it didn't get any help from programmers. While it was brilliant at a lot of the games, it couldn't get the hang of *Pac-Man*.

PHOTOS: VOA NEWS, AFFECTIVA ILLUSTRATIONS: JOE WALDRON

SHOULD WE LET PANDAS GO EXTINCT?

These black and white bears have been a conservation mascot for decades. But do they have a right to hog the limelight?

WORDS: **JULES HOWARD**

There is a skull that sits on a shelf on our wall. There is a hint of antiquity to it, though I must confess that it is a replica. Upon noticing the sharp teeth, children assume it is from a dinosaur. They place it on their heads and go "ROAR!". Adults know better: they assume it is from some sort of cat, because they see its large canine teeth.

They are both wrong. Neither the adults nor the children ever notice the molars that have become stretched wide like those of a horse – an adaptation forged in the depths of China's bamboo forests to combat starvation. For the skull is actually that of an herbivorous bear: a giant panda, of course. There is always surprise when I tell people this, it's as if they've completely forgotten that there are bones under the skin of this celebrity teddy bear. This is understandable, because the panda has become so much more than just 'a bear'.

Pandas are a conservation mascot, a marketing tool, a symbol of the wild we are losing, and a conservation big-hitter worth paying to save. Or so we're told. Yet after five decades of our conservation efforts they have offered us little 'bang for our buck', and a bitter frustration has begun to play out publicly about their worth in recent years. Like Premier League footballers who fail to live up to their hype, nasty slurs about the pandas have crept onto the pages of newspapers and websites, blaring things like "Stuff the pandas!". Meanwhile, wildlife presenter and naturalist Chris Packham has lamented their costly conservation as pointless and said we should "let them go with a degree of dignity". ▶

PHOTO: GETTY

"In 2016, Hua Yan became the sixth panda to be released back into the wild"

But are they really a pointless animal? Do they have worth? These are interesting questions to dwell upon, for if you look closely at pandas you begin to understand that wildlife conservation is far from just black and white. It is shades of grey, and is only given value by us.

A CUDDLY CONCEPTION

Let's start at the beginning. How did pandas come to capture the public's imagination? What is it about them that we came to love?

In 1966, while panda conservation was still in its infancy, zoologists Ramona and Desmond Morris put together a list of why pandas would come to creep into the public consciousness in their book *Men And Pandas*. Included in their list was the fact that pandas (appear to) have big eyes; that they sit up vertically like us and have no tail; they are playful and round; and they lack any obvious sexual features that "embarrass the human eye and work against the animal's popularity". According to the authors, pandas spent millions of years of going it alone on their own evolutionary journey, and then they hit the publicity jackpot simply because natural selection happened to produce a creature that we humans consider cute and unthreatening. That was all it took.

The rest was history. We responded to news of their downward spiral by showering them with concern and cash. And we still do.

Today, panda conservation is big business. Although official financial figures from China are hard to come by, wild panda conservation is aided in part by the rental costs of captive pandas, which are housed in zoos around the world at a cost of hundreds of thousands of pounds each year.

Scotland's Edinburgh Zoo, for instance, pays £600,000 annually for the privilege of housing two pandas named Tian Tian and Yang Guang. Extrapolating up conservatively, the contribution to wild panda conservation from captive pandas in zoos comes to over £20m each year.

BELOW: **Zoologist Desmond Morris said that we love pandas because they're playful, appear to have big eyes, and look cuddly**

Are pandas worth it, then? Is all of that money being well spent? That depends. If your definition of success is the reintroduction of captive-bred pandas to the wild, then the answer is probably no. In 2016, Hua Yan, a two-year-old panda bred in captivity, became the sixth panda to be released back into the wild, and that's after 50 years of effort. No real success there then – or at least not yet.

But if your definition of success is about panda numbers in the wild, then yes, undoubtedly there is reason to be cheerful, for wild panda numbers appear to be rising at last. In 2003, there were only 1,600 wild pandas remaining. Now, 14 years later, there are nearer 1,850 – an increase of 16 per cent. In fact, as of September 2016, giant pandas are no longer considered officially endangered, they are now listed as merely 'vulnerable' by the IUCN, the global record-keepers of the fates of dwindling species. Thanks to a marked decrease in poaching and an

PHOTOS: PRESS ASSOCIATION, NATIONAL GEOGRAPHIC/AMI VITALE

ABOVE: **Scientists don costumes and douse themselves with panda pee in an attempt to prevent the animals becoming attached to humans**

expansion in the species' protected habitat, the future of China's wild pandas looks more secure than before.

It is likely that this trend will continue, so one could argue that the conservation money has been a great success. A species has been saved, by us – or at least by those people who visited zoos to gawp at captive pandas, or gave money to the international wildlife charities that represent them.

STEALING THE LIMELIGHT

But £20m or more each year. That's a vast amount of money. Could that cash be better spent elsewhere? After all, there are many other species far more threatened than pandas on the IUCN's list, few of which may be granted more than a few thousand pounds between them in terms of conservation money.

What about the Nubian flapshell turtle, for instance – a funky-looking reptile whose numbers have fallen by 80 per cent in just two generations? Or the Kurdistan newt, which is restricted to just four streams in an area covering less than 10km^2? Or my personal favourite, the geometric tortoise – another critically endangered creature afforded little by way of public understanding or interest. When it comes to wildlife campaigns asking for your cash, these species are unlikely to appear in the advertisements. Couldn't they do with some of our cold hard cash too? The answer is yes, of course they could.

A 2012 analysis by conservation scientist Dr Robert Smith and colleagues highlighted just how hard it is for many threatened species to get the airtime they deserve. Of the 1,200 mammals then threatened with extinction, just 80 species were used by conservation organisations to raise funds. And which species did they use? Predictably, it was generally those creatures that had large, forward-facing eyes.

ABOVE AND RIGHT: **The geometric tortoise and the Kurdistan newt don't receive much funding, despite being critically endangered**

This was a particularly depressing finding. The message that reads loud and clear is that we hold up a magnifying glass to nature, and see only our own reflection in the glass. We buy cute and always have – and the marketeers know it. In this way, it is probably true to say that pandas benefit from having a body that's shaped like a teddy bear. The Kurdistan newt just cannot compete. But this is not the fault of pandas – it's the fault of humans for being so easily fooled.

SAVE THE PANDA, SAVE THE WORLD

At this point, let's consider the argument from the other way around. Why *shouldn't* conservation organisations use the marketing power of pandas to further their worthy aims? What's so bad about cashing in on a beautiful bear if by saving it, we may save thousands of other species with whom it lives in the wild?

For this reason, pandas and certain other 'charismatic megafauna' are often given special value, because they can act as 'umbrella species'. The argument goes that if these animals are protected, then so too are the other creatures that live within their shared habitats. Looking after a bear or a cheetah or tigers, for instance, protects everything else – the spiders, birds, lizards, mites and frogs – that may happen to share the same habitat, but that no one really cares enough about.

Conservationists use this argument quite a lot, so how does the 'umbrella species' claim stack up? Pretty well, at least in theory. A 2015 study by Prof Stuart Pimm and Binbin Li from Duke University highlighted that protecting the giant panda's habitat enhances the survival prospects of many other species including 70 per cent of forest birds, 70 per cent of mammals and 31 per cent of amphibians found nowhere else on Earth. While the umbrella analogy is laudable on paper, some conservationists have mixed feelings about it.

"Habitat protection is pretty vital," argues Anne Hilborn, a carnivore biologist from Virginia Tech, "but many species face lots of other threats – overexploitation, pollution, climate change, disease – that preserving habitat alone will not protect against."

Habitats are more complex than we like to imagine, and they may not always remain unchanged once protected. Dr Sarah Henshall of Buglife, an NGO that focuses on the conservation of invertebrates, sees potential in using charismatic megafauna such as pandas to secure wider species protection but also urges caution.

"Improving the quantity, quality and connectivity of habitat will certainly benefit invertebrates," she explains. "However, the devil is in the detail. The rare stuff is rare for a reason – species may need very specific conditions and microhabitats to prosper, so a broad-brush habitat approach to saving species will not always work."

In other words, umbrella species do have their uses, but lesser species are bound to get wet in the face of relentless, driving rain made worse by

"What's so bad about cashing in on a beautiful bear if by saving it, we may save thousands of other species?"

PHOTOS: GETTY X2, ZIGMUND LESZCZYNSKI / NATIONAL GEOGRAPHIC

human interference. Ultimately, only the creatures holding the umbrella may stay dry. Pandas are one of them because, like it or lump it, we value them more than most. It's for this reason that their fortunes are finally on the up.

PANDAS WITH PURPOSE

Since the giant panda has been downgraded from 'endangered' to' vulnerable', I believe it has taken on a new role. As well as offering glitz and glamour, the panda is now one of the minority of creatures that is being saved. It is a success story, 50 years in the making, and it has happened on our watch. We should be much more proud of pandas than we are – we need more success stories like them.

Pandas have quite clearly been overused as a conservation character in recent decades. But perhaps as audiences become more savvy and questioning about the dreams they are being sold, we will see new umbrella species that come to dazzle us, and we'll attain a wider, deeper understanding of how conservation really works.

I really hope so. For I can't help but wonder whether in the future it may not be us that saves the panda, but the pandas that end up saving us. If these much-loved bears can encourage us to look after our ecosystems, then we could make the world a healthier place and improve our chances of survival.

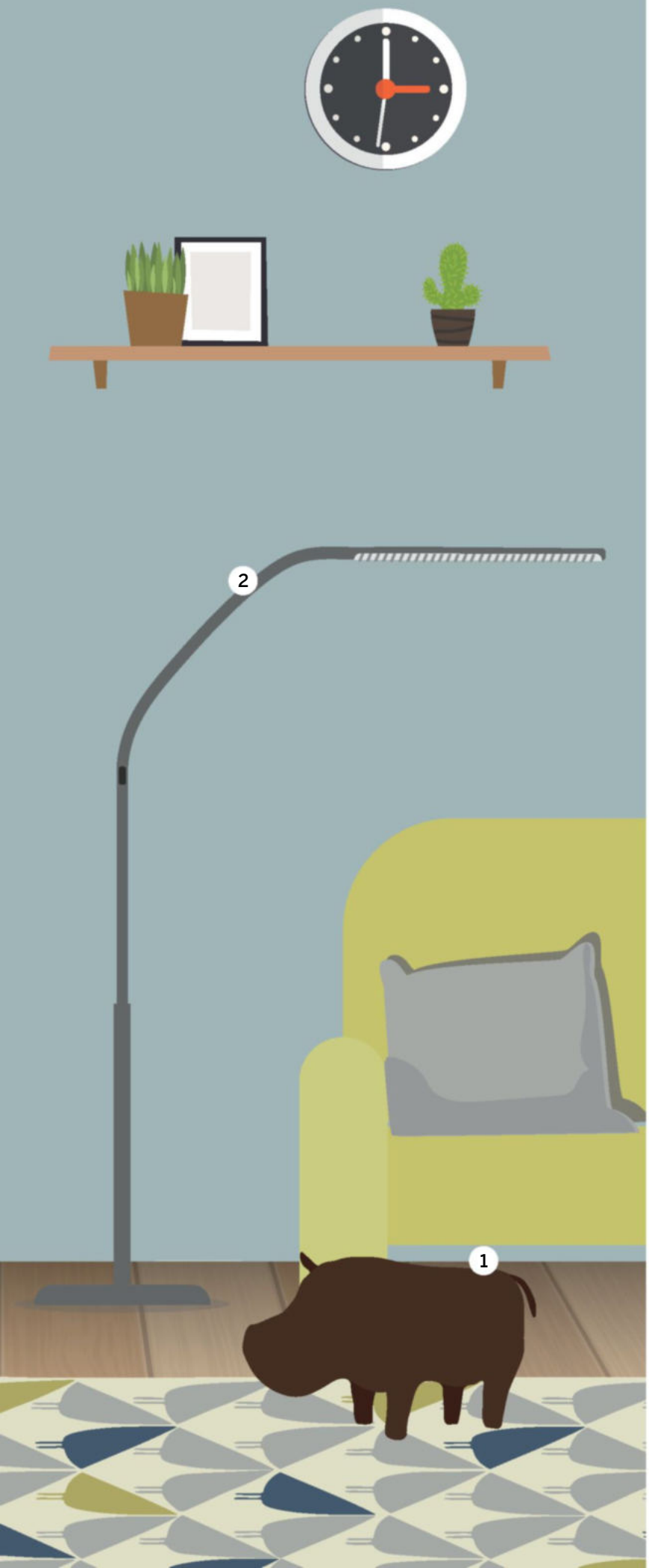
Jules Howard (@juleslhoward) is a freelance zoologist, presenter and author. His most recent book is *Death On Earth* (£16.99, Bloomsbury) **juleshoward.co.uk**

BELOW: **Pandas, like this tiny, three-month-old cub, are incredibly difficult to breed in captivity**

PHOTO: GRIGORIJ RICHTERS/ASTEROID DAY

LIVE IN LUXURY

Planning a film night, or looking to improve your living room set up? Bring some personality to your house's most important room, with these six stylish ideas



1 Leather Hippo Footrest

Add a little personality and comfort to your film nights with this charming leather hippo footrest. Handmade from high quality leather in the UK. £299
thepresentfinder.co.uk

2 Daylight D35117 Slimline LED Floor Lamp

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3 SoundTouch 300 Soundbar

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6 Hoop coffee table

This unusual and stylish table makes a great addition to your neo-retro living room and comes in just about any colour you fancy. A handmade statement space and stylish storage solution.
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Credit: iStock

ILLUSTRATION: BEN THE ILLUSTRATOR

AUTONOMOUS VEHICLES CAN TAKE MUCH OF THE DANGER OUT OF DRIVING, BUT THEY ALSO PRESENT US WITH NEW PROBLEMS TO SOLVE. SO WHAT NEEDS TO BE FIGURED OUT BEFORE THE TECHNOLOGY GETS THE GREEN LIGHT?

Words: Rob Banino

Remove humans from the driving equation and cars will be safer. That's the thinking behind the push for autonomous vehicles – and the reason why, like it or not, they're coming to our roads.

"Autonomous vehicles reduce the risk of collisions, and that's recognised by insurers," says Ian Crowder from the Automobile Association (AA). "If the technology proves to be much more reliable than humans, who can be subject to tiredness, stress or distraction… there's every possibility that situations that would typically lead to collisions will be removed."

Safer cars and safer roads are attractive prospects, in both human and financial terms. According to the Department of Transport and the Department of Business, Innovation and Skills, the intelligent mobility market is estimated to be worth £900bn annually globally by 2025. This is why car manufacturers are pushing to develop the vehicles, and why the UK government is investing heavily to help them. Last year saw £39m of a £100m fund awarded to projects working on enhanced communication systems between vehicles and roadside infrastructure, and trials of autonomous vehicles in Greenwich, Bristol and Milton Keynes.

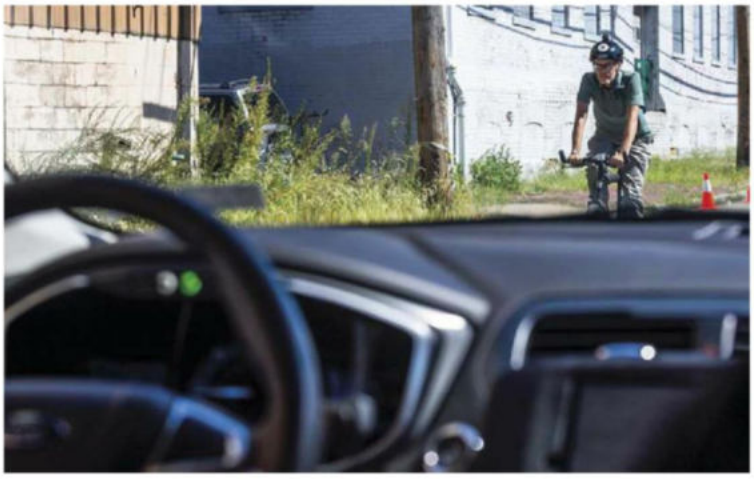
But what's controlling these cars if there's nobody at the wheel? The short answer is a lot of extremely sophisticated technology. Audi, the first manufacturer to receive permits to test autonomous vehicles on public roads (in Nevada in 2013 and Florida in 2014), uses differential GPS (said to be accurate to within a few centimetres), 12 radar sensors (to scan the road in front of the car), four video cameras (to spot road markings, pedestrians, objects and other vehicles), a laser scanner (that emits nearly 100,000 infrared light pulses per second, covering a zone of 145° on four levels around the car to profile its surroundings) and a powerful computer to process everything the sensors detect. And all of those systems need to work together so that the car always knows where it is, where it's going and what's around it.

SEEN IN A BAD LIGHT

Some of these systems have been shown to work, and have found their way into cars with adaptive cruise control or parking assist. But relying on them to safely conduct a journey on open roads alone is a big step. Still, it's a step that many companies including Tesla, Google, Fiat Chrysler, Renault-Nissan and Uber (with the help of Volvo) are in the process of taking. Although their efforts have, on the whole, been safer than normal cars (in terms of the number of accidents per miles driven), they have encountered problems. For example, Renault-Nissan's CEO Carlos Ghosn admitted to CNBC that the system in its vehicles is confused by cyclists "because sometimes they behave like pedestrians, and sometimes they behave like cars".

Meanwhile, the cameras on Tesla's vehicles have been said to struggle with the glare from sunshine, particularly at dawn or dusk. And sunlight's not the only natural phenomenon that can throw a spanner into the works: rain interferes with what a driverless car 'sees' through its cameras, and reduces the effectiveness of any laser scanners, as the drops can bend and reflect the light pulses.

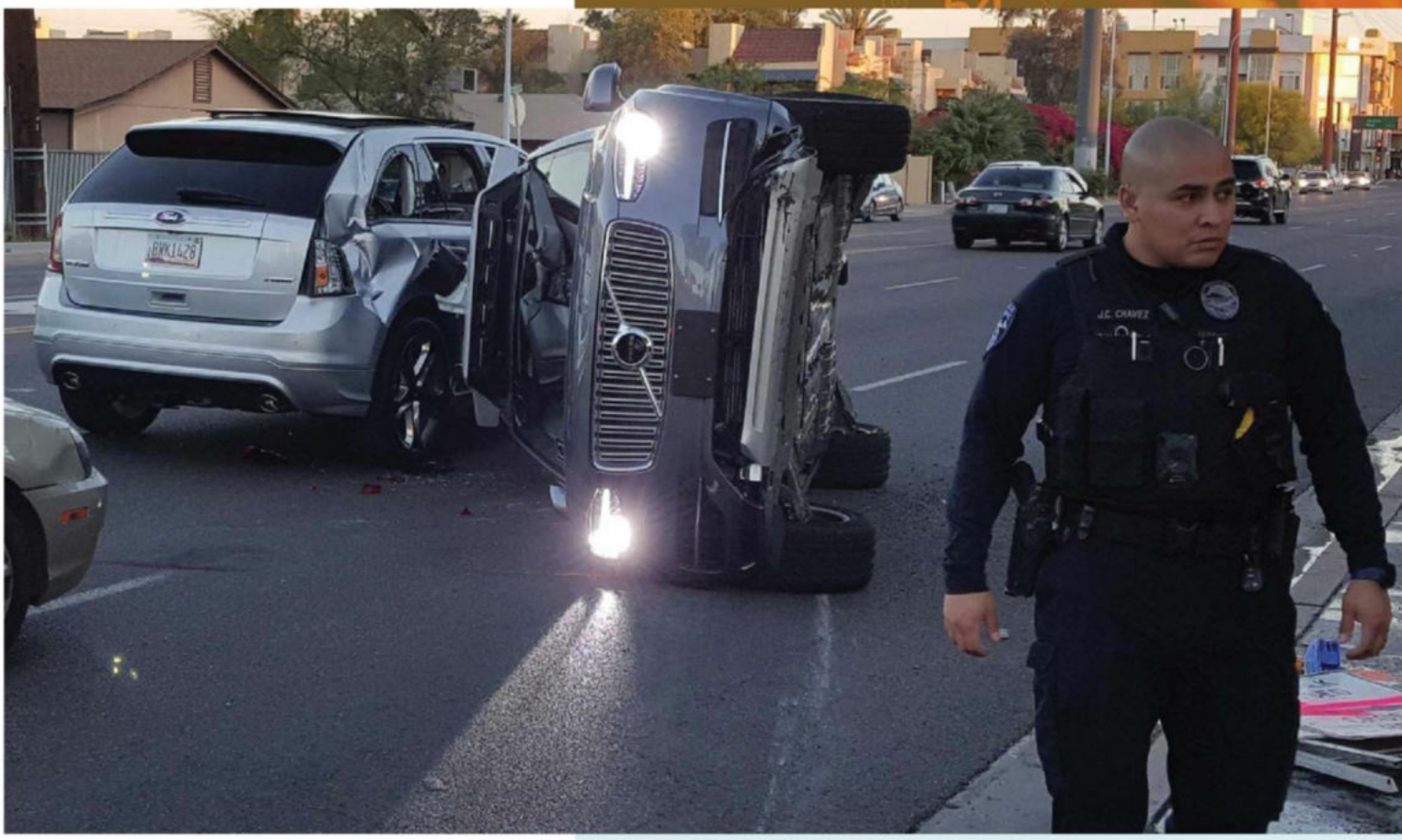
Problems like these have led to some high-profile incidents. Last December, Uber had to withdraw the 16 test vehicles it was trialling in San Francisco after California's Department of Motor Vehicles revoked the cars' licences. The local authority said that the ride-hailing company didn't have a permit to operate autonomous vehicles on the city's roads, but its decision came after footage emerged of the



BELOW: **Cyclists ride on roads and pavements, which can confuse the technology in autonomous cars**

"Given that people's lives are at stake if an autonomous vehicle fails, perhaps the roads aren't the best place to test the technology until we can be sure it's more reliable"

PHOTO: GETTY X2, REUTERS



vehicles running red lights and veering into cycle lanes. Then in March, Uber temporarily suspended its self-driving programme after one of its cars flipped onto its side in a crash in Tempe, Arizona.

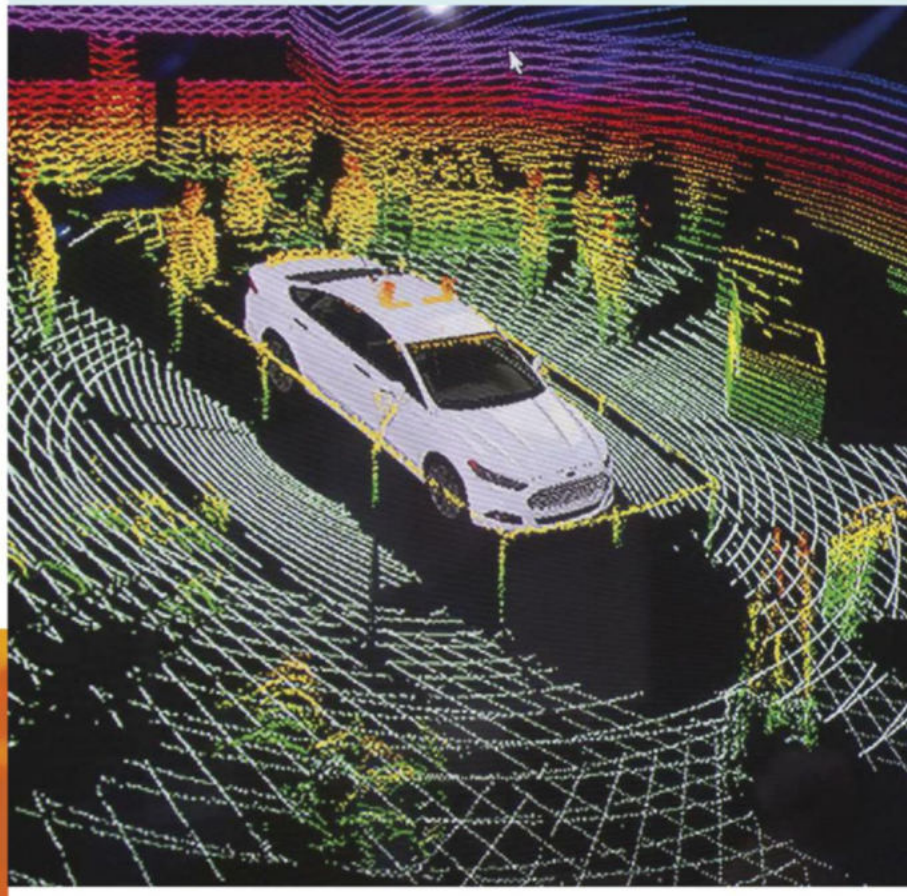
Perhaps the most notable failure happened in May 2016, when a Tesla Model S running in Autopilot crashed into a truck in Florida, killing driver Joshua Brown. Tesla told investigators that the Autopilot was not at fault, but there had been a "technical failure" of the automatic braking system.

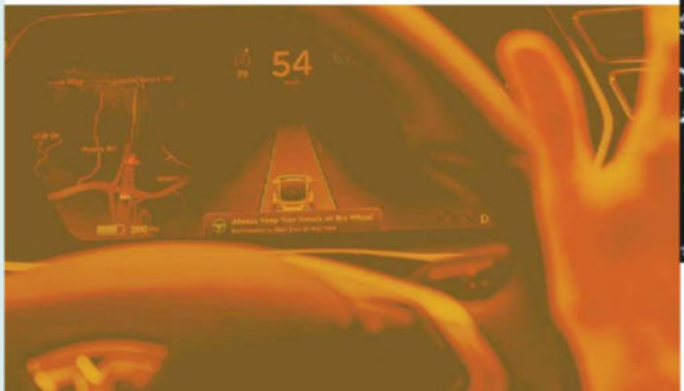
TESTING THE COMPETITION

Failures are to be expected during the testing and developmental phases. "It's only through using the technology and trying it in real life that it's going to be improved, because even the best developers are not going to recognise every possible scenario that an autonomous vehicle might encounter," Crowder points out. But given that people's lives are at stake if an autonomous vehicle fails, perhaps the roads aren't the best place to test the technology until we can be sure it's more reliable. Especially when we could put autonomous vehicles through their paces in another way: motor racing.

ABOVE: **Fortunately, there were no injuries when an Uber self-driving car crashed in Arizona**

BELOW: **Autonomous vehicles use a wide variety of sensors to 'understand' their surroundings**





HOW COULD DRIVERLESS CARS CHANGE MOTORING?

It's early days for autonomous vehicle technology but it has the potential to have some profound effects. Especially if it completely rules the driver out of the equation...

PARKING

Some cars already have 'parking assistance' that allows the vehicle to manoeuvre itself into tight spots. But they require the driver to be there 'just in case'. If a driverless vehicle could be trusted to park itself, it could drop you off at your destination and find a space on its own.

LEARNING TO DRIVE

It's likely that anyone operating a vehicle, autonomous or not, will still require some sort of training in order to do so. But the arrival of autonomous vehicles is expected to result in changes to the Highway Code and possibly the skills taught while a new driver is learning.

TAXIS

If a car can take you anywhere without you having to drive, why do we need taxi drivers? Uber has stated that its plan is to eventually operate an autonomous fleet. So while it may be goodbye to awkward conversations with drivers, there may also be considerable job losses.

SLEEPING

If autonomous vehicles reach a point where the controls can be entirely handed over to the car, there'd be no need to stay awake during the journey. You could simply get in, buckle up and nod off. That'd certainly make the M6 a lot more pleasant...

TOURISM

You're visiting a city and you want to see the sights. Would you rather get on a tour bus, or hop in a car and let it ferry you from one destination to the next? While might be fun to jump on an open-top bus, there's always the threat of rain spoiling the trip.

ROAD HAULAGE

Goods reach us aboard vans or lorries, but drivers can only be at the wheel for a specific number of hours each day. Autonomous vehicles could make long trips without rest stops. Faster journeys and greater fuel efficiency equals lower costs... and potentially another career in jeopardy.

"In many ways we're ahead of the industry," says Justin Cooke, the chief marketing officer of Roborace, the championship for autonomous electric vehicles that's expected to debut this year. "Roborace was developed to evolve technology that will be used on the road, and accelerate the speed at which both electric and autonomous technology is being tested for road cars."

But despite the speed and competition, racing is arguably a less extreme test environment as there are no pedestrians, roadworks, junctions and crossings to worry about, and all of the traffic's moving in the same direction – albeit very fast. Hence, unlike the autonomous vehicles being trialled on the road, the Roborace cars won't have someone onboard to take control if something goes wrong. So what happens if a car goes awry during the course of a race?

"All the cars will be equipped with a 'safe stop' that the engineers control back in the pit," explains Cooke. "If the car goes off course for any reason, it can be brought to an immediate stop using this button. In fact, it's even safer than a human-driven race car, as the robocar can literally stop instantly, because there's no delay from a human reacting to a problem and then performing an emergency stop."

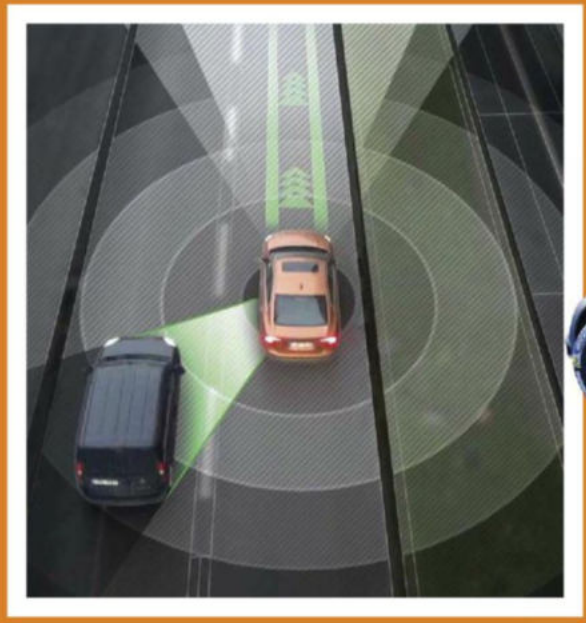
The cars' first competitive public outing in February brought mixed results. Two driverless cars took to the city-centre circuit ahead of the Formula E race in Buenos Aires but only one finished. The other overshot a bend and crashed into the barriers – although, encouragingly, the car that completed the race not only achieved a top speed of 186km/h (116mph) but also successfully avoided a dog that strayed on to the track. Another demo race is scheduled for the cars on 1 April.

THE BLAME GAME

Roadgoing autonomous vehicles don't have the luxury of a pit crew, however. Which is why the vehicles being tested on our roads need to have a qualified driver in the driver's seat ready to take control in case of emergency. It's a policy that's likely to be retained if – or more probably when – autonomous vehicles are given the go-ahead, meaning you won't be able to stumble out of a pub drunk and expect your car to drive you home.

But this approach creates more conundrums: if the 'driver' isn't actually driving, doesn't that make them a passenger? And if the driver fails to react correctly and has an accident, is it their fault or the car's? The more cynically minded might see this as a 'get out of jail free' card for manufacturers of autonomous vehicles. Uber blamed the instances of its cars running red lights in San Francisco on human error, and there are reports that Joshua Brown was watching a film when his Tesla crashed.

"It does raise issues for insurers, because you have the transfer of liability if there's a collision involving a driverless vehicle," says Crowder. "It's something that the insurance industry certainly needs to think about, and indeed *is* thinking about.



Volvo has been working on self-driving technology, using sensors that keep track of the road and surroundings

Roborace allows driverless technology to be tested, without putting drivers' lives in jeopardy

If it's a software failure that leads to a collision, there need to be fairly robust procedures in place to ensure that such a claim can be met promptly, and that there are the processes in place to do that."

The Association of British Insurers is pushing car manufacturers to ensure that autonomous vehicles can collect core data in the event of an accident, and that the information is made available to prevent drivers being unfairly blamed. The data would cover a period from 30 seconds before to 15 seconds after an incident, and provide a GPS record of the time and location of the incident; confirmation of whether the vehicle was in autonomous or manual mode; if, while in autonomous mode, the vehicle was parking or driving; when the vehicle went into autonomous mode, and when the driver last interacted with the system.

"If – or when – autonomous vehicles are given the go-ahead, you won't be able to stumble out of a pub drunk and expect your car to drive you home"

HIGH-TECH HACKING

But what if someone is controlling the vehicle who isn't the driver? In other words, what if an autonomous vehicle is hacked? This has already been proven possible with conventional vehicles: cyber security experts Charlie Miller and Chris Valasek have managed to take over various vehicles' electronic control units remotely. Hacking is therefore an enormous concern for everybody, not just in terms of losing control of the vehicle but also regarding what that vehicle could then be used for, as Crowder points out.

"[Hacking] is a concern and it's something that's often raised… it could open the way towards terrorism or other criminal activity. But that's a risk that's already there – with cars that have keyless technology, for example. Certainly, the manufacturers will need to be on top of the technology to make it hack-proof, but everybody knows that car thieves are often one step ahead," he says.

Being "one step ahead" means that the people who abuse the technology – the thieves and hackers – are often the ones who can design the best security systems. Uber certainly thinks so: the company hired Miller and Valasek shortly after they demonstrated what they could do to a car being driven miles away, using only a laptop.

Although autonomous vehicles have the potential to make our roads safer, there are still a lot of bugs to work out with the technology, and questions to answer regarding its use. The only thing we can say with any certainty is that it's going to be a long time before the human element is completely taken out of the driving equation.

Rob Banino is a freelance science and technology writer.

DISCOVER MORE

Watch editor Daniel Bennett try out the Autopilot feature on a Tesla at **bit.ly/tesla_test**

PHOTOS: VOLVO, ROBORACE ILLUSTRATION: BEN THE ILLUSTRATOR

: Jeff Forshaw and Brian Cox :

GUIDE TO THE COSMOS

Part II of IV

THE QUANTUM WORLD

How subatomic anarchy gives rise to everything we see in our daily lives

About this series

In this exclusive four-part series, physicists Jeff Forshaw and Brian Cox introduce us to the biggest ideas in modern physics and cosmology. What is the nature of time? What is everything made from? What happened before the Big Bang, and how will the Universe end? We'll delve into the deepest questions concerning the very essence of space, time, matter, and reality itself...

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What happens if you chop something in half, then in half again and keep on going? What do you end up with? Can you keep doing it forever? These simple-minded questions are profound and lead us into the bizarre world of quantum physics. Bizarre because, as we are about to find out, the world of tiny things is extremely different from the world of big things: it is a world where particles dance around each other according to rules ➔

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ILLUSTRATIONS: SAM CHIVERS, KATE COPELAND

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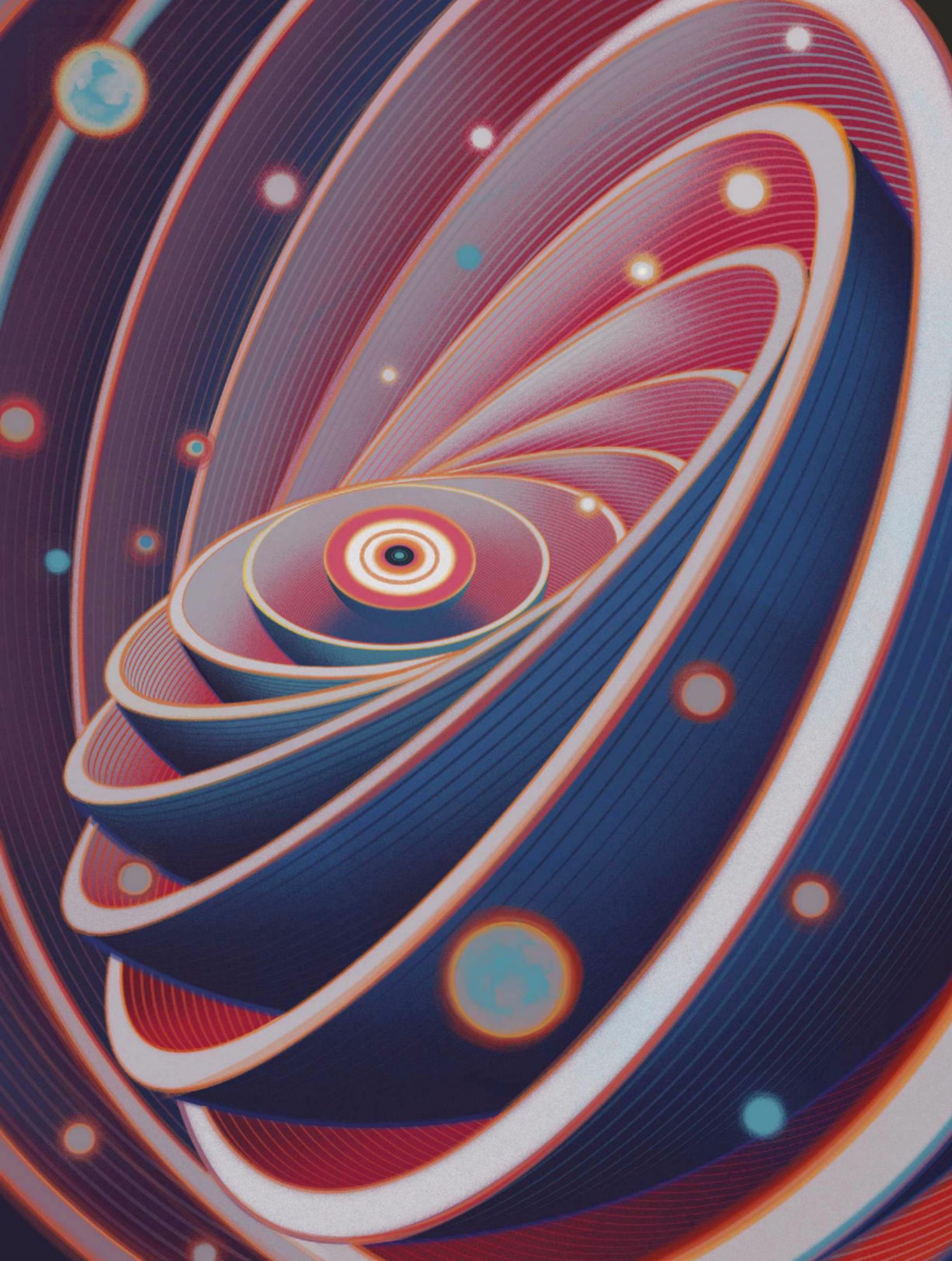


“As far as we can tell, quarks and electrons are not made of anything”

that completely defy common sense. Perhaps the most shocking aspect of quantum physics is that one particle can be in *several* places at the same time. (That previous sentence is worth reading a few times!) Clearly, these are no ordinary particles – they are tiny things that do not behave like miniature versions of big things.

INTO THE RABBIT HOLE

As far as physicists can tell, everything in the Universe is made up of tiny particles. For example, the molecules in your body are made out of atoms, and each atom is composed of a central nucleus surrounded by a cloud of electrons. The nucleus is about a trillionth of a millimetre in size and inside it is a bunch of protons and neutrons, which in turn are made up of quarks. As far as anyone can tell, quarks and electrons are not made of anything smaller. That might just be because we haven't yet built a sufficiently powerful microscope to look inside them, but there is another possibility: it might be impossible to break these particles apart. For this reason, electrons and quarks are two of just a handful of different types of particle that we think of as 'elementary' (we will be exploring the other types of elementary particle in the next article in this series). Okay, so how do these elementary particles move around?

The first thing we need to appreciate is that it is impossible to know what a particle will do next. What we *can* know is how likely it is to do a particular thing. For example, if we know that an electron is 'over here' at one particular moment then we can use mathematics to calculate how likely it is to be 'over there' at a later time. In other words, the best we can do is compute probabilities. This is not a feature of human ignorance – rather it is a feature of the Universe that the future is inherently uncertain. So how do we calculate these probabilities in quantum physics? This is where the fun really starts.

PHOTO: CERN ILLUSTRATION: SAM CHIVERS

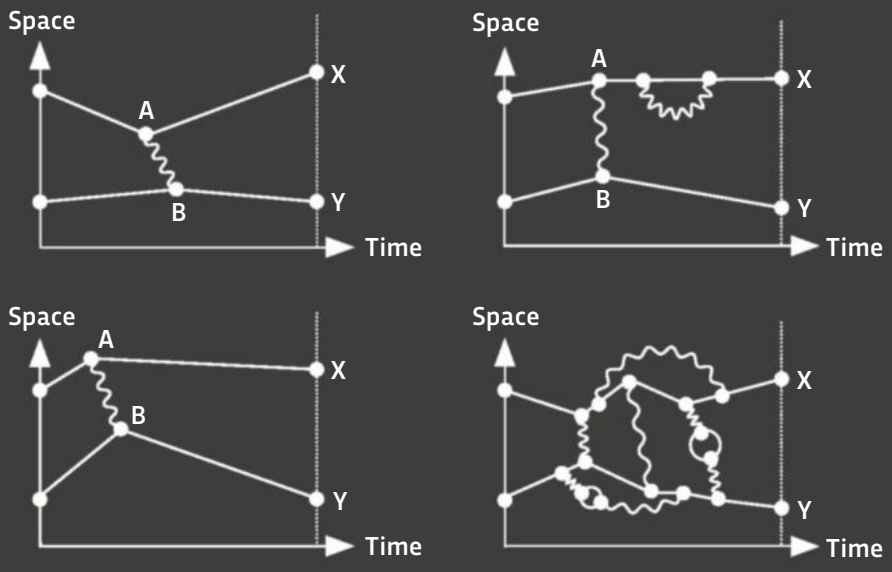
RESTLESS PARTICLES

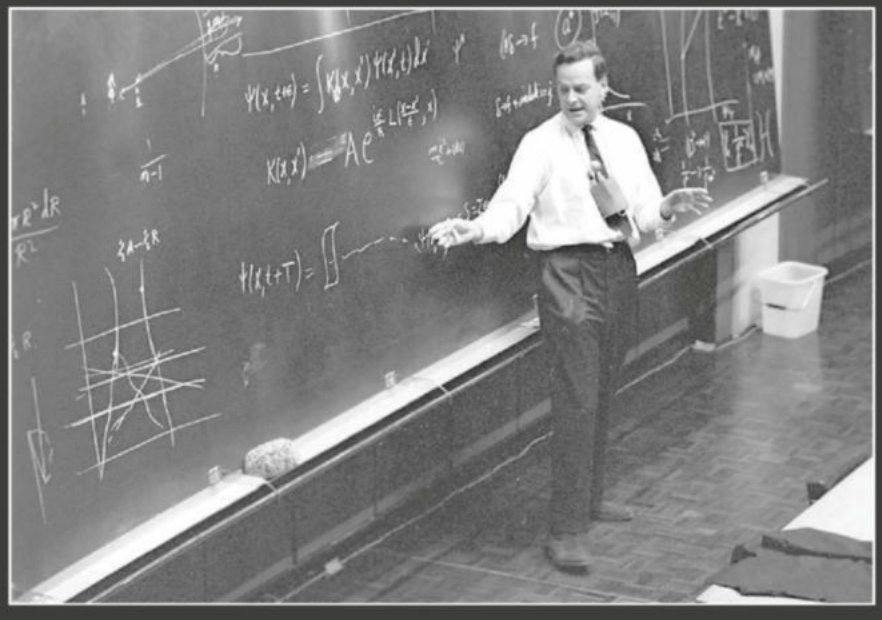
Let's plunge straight in and consider a specific example. For this, you need to look at the four pictures in 'The key idea' (right). These pictures show four different ways in which two electrons can travel to the points X and Y. In the top-left picture, one electron starts its journey from the upper dot on the left and the other starts its journey from the lower one. The first electron hops to point A where it does something interesting – it emits a particle of light (called a photon and denoted by the wavy line). The photon then hops from A to B, while the electron continues its journey and hops from A to X. The journey of the second electron is also interesting. It starts by hopping to point B where it absorbs the photon emitted by the first electron. After that, it hops onwards to point Y. Although this might seem quite unfamiliar, the rules of the game are really rather simple: electrons can

The key idea

EVERYTHING THAT CAN HAPPEN DOES HAPPEN

These pictures show four different ways in which two electrons can travel from their initial positions (denoted by the two dots on the left of each picture) to the points marked X and Y. Along the way, they can exchange a photon (or photons), denoted by the wavy lines. For each picture, it is possible to compute a number, and then we must add together all of these numbers to compute the probability that the particles will actually arrive at X and Y. Although we have drawn just four pictures, there are infinite possibilities: the electrons must travel by *every* possible route in order to arrive at their destination. It's one of the most mind-boggling aspects of quantum physics.





Richard Feynman developed diagrams to help show how subatomic particles behave

Glossary

ELEMENTARY PARTICLE

These tiny particles aren't made up of anything smaller (to the best of our current knowledge). Everything in the Universe appears to be made up of just a handful of different types of elementary particle. Two of these – electrons and quarks – are the main ingredients of atoms.

FEYNMAN DIAGRAM

Named after Richard Feynman, these pictures provide a way to visualise how the elementary particles move around and interact with each other. We can use the diagrams to compute the probability that something will happen to the particles.

PROBABILITY

A number between zero and one corresponding to the odds that something will happen. For example, the probability that a rolled dice will show a six is 1/6 = 0.167. This means that on average 16.7 out of every 100 rolls will register a six. Probabilities are all that we can calculate in quantum physics. This inherent unpredictability of nature cannot be circumvented by knowing more.

QUANTUM PHYSICS

This explains how atoms and other tiny things work. It replaces Newton's laws of motion, which fail to describe atoms. Quantum physics is counterintuitive – most remarkable perhaps is that a particle can simultaneously be both 'here' and 'there'.

UNCERTAINTY PRINCIPLE

Named after Werner Heisenberg, this is the contrary idea that the more accurately we know the location of a particle at some moment in time, the more likely it is that the particle will immediately jump far away from that point.

hop from one place to another and they may or may not emit or absorb photons… that's all there is to it.

You can use these simple rules to draw your own pictures of how the electrons might hop and branch their way to points X and Y – we have shown three more possibilities. The last one (bottom-right) is quite fancy and involves lots of photons, but hopefully you can see that it is still just a matter of electrons hopping around and emitting or absorbing a photon.

Pictures like these are called Feynman diagrams (after the US physicist Richard Feynman) and they describe how particles interact with each other – in our case, the two electrons interact via the exchange of photons. In fact, all of the particles in nature interact in ways very similar to those we just described. There are a few more types of particle (other than electrons and photons), and a few more rules to consider, but the basic idea of how particles interact is the same. Nice pictures don't really amount to very much, though – we need to use them to help us calculate the probability that the electrons will end up at the specific points, X and Y. Remember, calculating the probability that something happens is the aim of the game in quantum physics.

EVERYTHING THAT CAN HAPPEN…

The lovely feature of Feynman diagrams is that they are not just pretty pictures. They can be translated into mathematics. Specifically, for every hop an electron makes (so for every straight line in a Feynman diagram) we can assign a particular number (the size of the number depends on how big the hop is). Similarly, every time an electron emits or absorbs a photon, there is a number. All of these numbers should be multiplied together to obtain one final number for each graph. In other words, we can calculate a number for each of the four graphs in 'The key idea'. Add those numbers together and you get the probability of finding one electron at X and the other at Y*.

> Quantum theory underpins our modern world"

Now, something extremely weird is going on here. To calculate the probability that something specific happens, the rules say that we must take into account *all* of the possible ways that this thing *could* happen. In the case of our pair of electrons, it seems we have to consider that the electrons reach X and Y via all possible routes. If we used 'common sense' and supposed that each electron really travelled along only one of the possible routes, then we would not get the correct answer for the probability. It really is as if the answer to the question "how did the electrons reach X and Y?" is "they went via every possible route". If this sounds crazy to you, then you are in good company, because it runs counter to our everyday experience. Experience has fooled us into imagining 'things' uniquely exist and move around along definite trajectories through space. The possibility that this idea might be wrong is at the heart of quantum theory.

As we have seen, the rules of quantum physics are quite simple. Once we have the rules for how electrons and photons can jump around, we can draw Feynman diagrams and compute probabilities that can be tested in experiments. And these are not esoteric calculations either: they allow us to compute how atoms behave, which is crucial for understanding chemistry. They are also key to understanding how semiconductor devices work, and these form the basis of today's technology. In other words, quantum theory underpins our modern world.

* Actually, the numbers are a special type of number known as 'complex numbers' and the probability is obtained by adding together the complex numbers for each possible route to X and Y. But to get the main idea, it isn't necessary to know about complex numbers.

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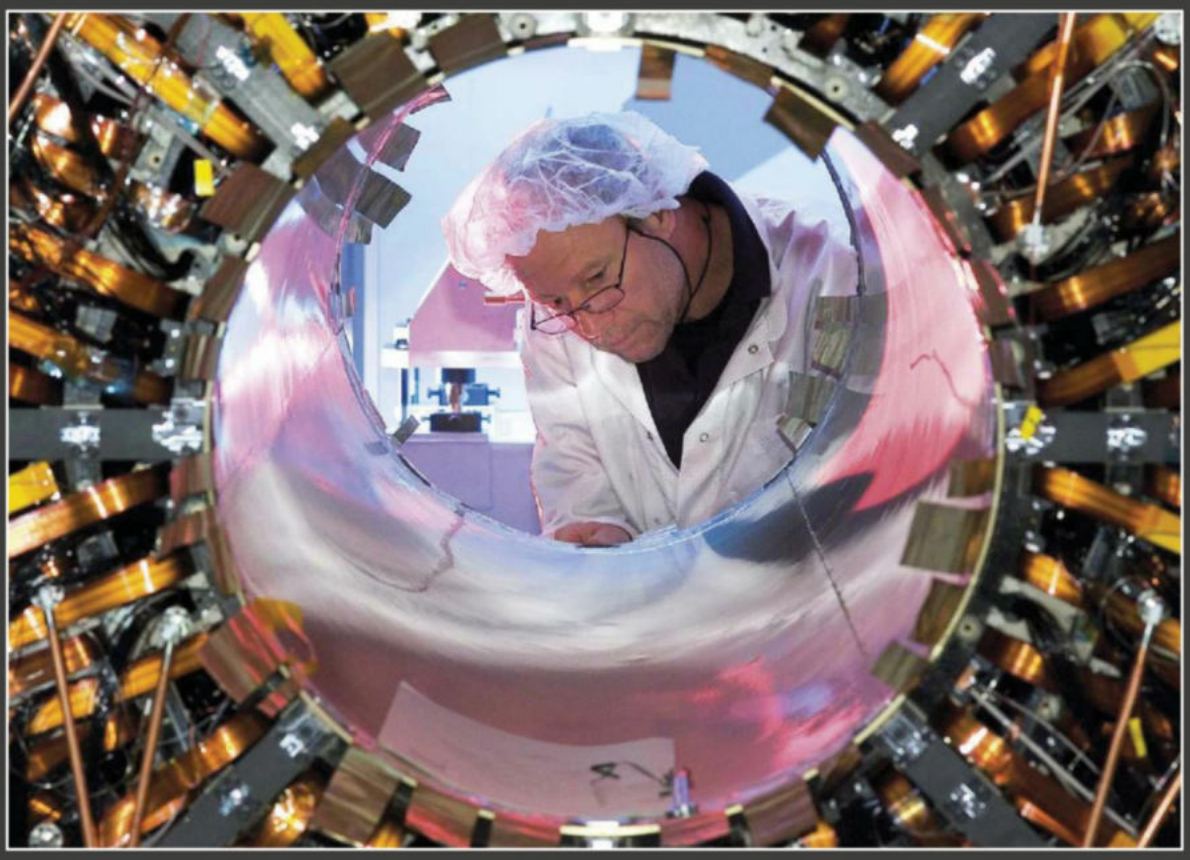


An engineer works on the ATLAS experiment, which hunts for the Higgs boson as well as particles that could make up dark matter

Quantum physics in five steps

1.

Everything in the entire Universe is made up of elementary particles that constantly interact with each other. These particles include the electron, quarks and – of recent interest – the Higgs boson.

2.

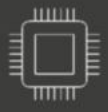
It is not possible for us to know exactly how these subatomic particles will move around. The best we can do is to calculate the probability of something happening.

3.

To calculate the probability of an electron moving to point X, we assign a number to each route, then add the numbers together. We have to consider that the electron travels by *every* possible route.

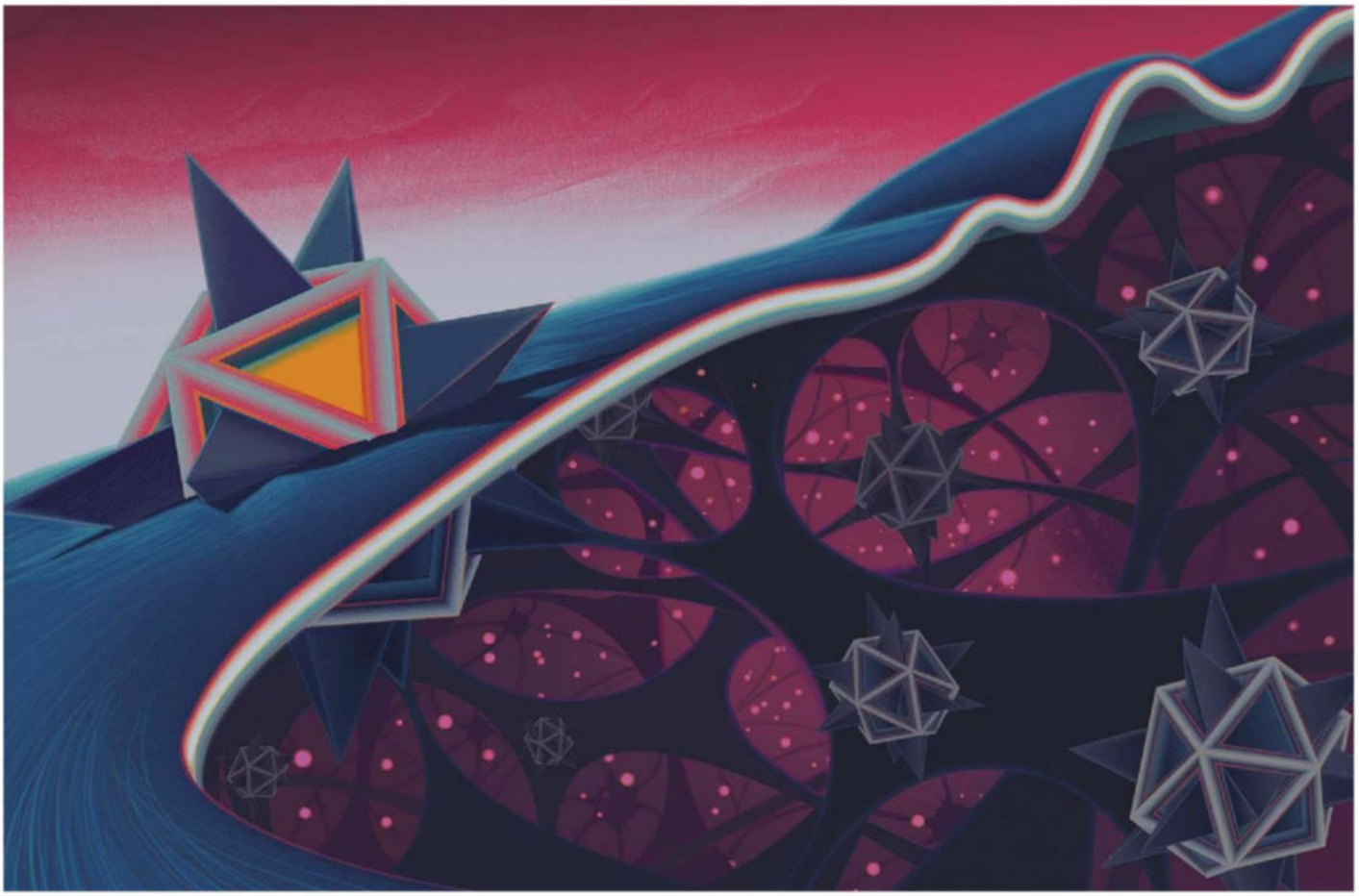
4.

Particles hop around like crazy, emitting and absorbing other particles as they go. Remarkably, the regular, orderly world that we experience emerges from this subatomic anarchy.



5.

The modern world is built using technology that relies on our understanding of quantum physics, from lasers and medical scanners to the silicon chips that power our computers and smartphones.



The trouble is that nature's quantum rules lead to a picture of the microworld that is pretty much impossible to imagine. This is probably the biggest challenge to anyone trying to understand it. We have to concede that the way we imagine the world is limited – we simply cannot conceive of things that are both 'alive' and 'dead', or 'here' and 'there', at the same time. But it seems that this is how the world actually behaves – the Universe is far richer than our imagination can grasp. The bottom line, then, is that although the rules might be weird, they can be used to make precise mathematical predictions concerning the real world.

"We simply cannot conceive of things that are both 'alive' and 'dead', or 'here' and 'there', at the same time"

THE WORLD WE SEE

Although we have been talking about the rules governing how particles move around, we have so far been careful not to say what those rules are in any detail. That's because the details require a knowledge of mathematics beyond what we can cover here. We can give a flavour of what's involved, though, by asking what happens to a particle whose position in space is perfectly well known at some moment in time.

Before the 1920s (which is when quantum theory first really established itself as the new order in physics), the answer to the question "what happens to a particle if it is left alone?" was thought to be self-evident: nothing happens to it; it just hangs around doing nothing. This is Isaac Newton's first law of motion. But, for small enough particles, Newton couldn't be more wrong.

The correct rule is that a particle, whose position is known at some moment in time, will leap off and could equally likely be found more or less anywhere else at any later instant. In fact, the particle really ought to be considered as occupying all possible locations in space simultaneously a mere moment after it is released from its original, known, location. This is the essence of Werner Heisenberg's famous Uncertainty Principle, and such spectacularly bizarre behaviour really is the way that tiny things move around. Large things, such as sofas and washing machines, are built from tiny

PHOTO: CERN ILLUSTRATIONS: SAM CHIVERS

Peter Higgs, who used purely theoretical ideas to predict the existence of a new particle in the 1960s. The particle, now termed the Higgs boson, was finally discovered using the Large Hadron Collider at CERN in 2012

"Apart from quarks, electrons and photons, we now know that the Universe contains other elementary particles"

particles, so you might be forgiven for wondering how such anarchic behaviour at the subatomic scale can lead to the mundane behaviour of everyday objects. After all, your washing machine does tend to stay in the same place from one day through to the next.

But remarkably, the anarchic rules operating at the subatomic level do lead to the everyday behaviour of big things. This is because, as we've already discussed, particles don't tend to occupy precisely known locations at some instant in time. Instead, they're in several places at once. Let's imagine one such particle, an electron in an atom in your body, say. At any given moment in time, the electron simultaneously occupies lots of different locations surrounding the atom. To compute the chances of it being found at a position X, far from your body, some time later, we need to add together the numbers corresponding to all of the ways the electron could hop from one of its original locations to X. The magic is that, although the numbers can be big for any particular hop to X, when we add the numbers for all possible hops together we get a tiny number. In other words, the electron is highly unlikely to be observed at X, far away from its parent atom. It seems that our regular and orderly world is an emergent feature of a seething maelstrom of activity on the subatomic scale.

Apart from quarks, electrons and photons, we now know that the Universe contains other elementary particles. There are the muon and tau particles, which are like heavy versions of the electron; three types of neutrino; W and Z particles; gluons; and, of most recent interest, there is the Higgs boson and perhaps (though not yet seen) dark matter particles. All of these hop around, emitting and absorbing other particles according to a set of mathematical rules. In next month's article, we will turn our attention to these elementary particles. We will see what role they play in shaping our Universe, and discover how the rules governing their behaviour are underpinned by the most beautiful of ideas.

Jeff Forshaw is professor of particle physics at the University of Manchester. He has co-authored three popular science books with Brian Cox.

Brian Cox is professor of particle physics at the University of Manchester and the Royal Society professor for public engagement in science. His BBC TV and radio work includes *Wonders Of The Universe*, *Forces Of Nature*, *Stargazing Live* and *The Infinite Monkey Cage*.

DISCOVER MORE

To learn more about the strange workings of the quantum world read Brian and Jeff's *The Quantum Universe: Everything That Can Happen Does Happen* (£9.99, Allen Lane).

Brian and Jeff's latest book is *Universal: A Guide To The Cosmos* (£25, Allen Lane).

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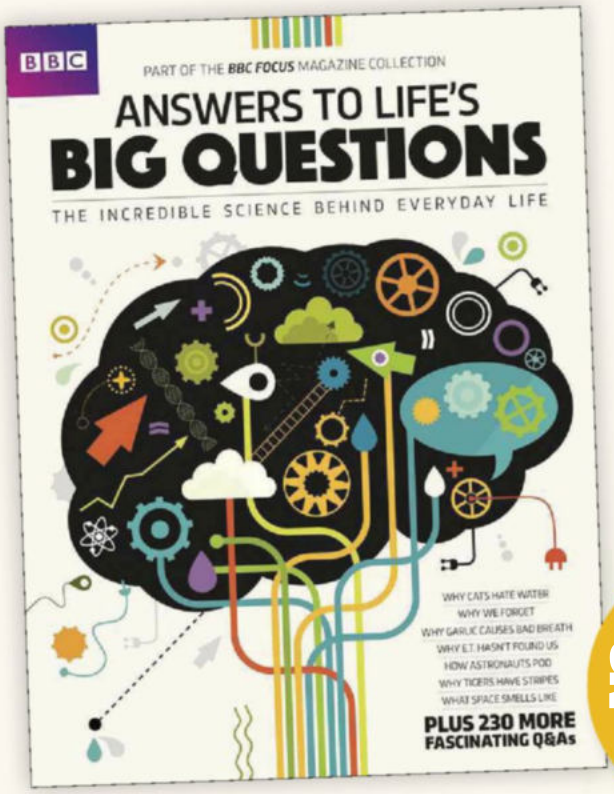

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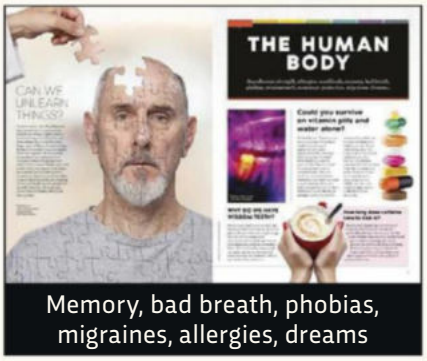

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HELEN CZERSKI ON... THE HIDDEN LIFE OF A LEAF

"THE STRUCTURE IS FANTASTICALLY CLEVER AND DELICATE, DESIGNED TO MAXIMISE PHOTOSYNTHESIS"

Leaves are green. It's one of those statements that is so self-evident you could easily reverse it: we can all agree on what colour green really is because it's the colour of a leaf and it's pretty much the same for all leaves. But while making a lasagne the other evening, I started to wonder whether we *really* know what that colour is. I was microwaving spinach in batches before chopping it up, and the difference in colour between the fresh spinach going into the microwave and the growing pile of cooked spinach was really striking. What went in was a cheerful light green, but what came out was much darker. Why the change? And which colour is the real green?

The leaves are the powerhouse of a plant: they're the flexible organic factory in which light fuels a reaction between carbon dioxide and water to make sugar. The actual work is done inside chloroplasts, self-contained pouches of chemical activity that sit inside the cells in the middle of the leaf. And the most important chemical of all is the chlorophyll molecule, the green pigment responsible for harvesting light. This lies within the chloroplasts and is what makes the spinach look green – chlorophyll absorbs red and blue light very strongly, mostly leaving the green alone.

But it turns out that the structure of a spinach leaf isn't just packaging for chlorophyll. The leaf structure is fantastically clever and delicate, specifically designed to maximise photosynthesis. Each chloroplast needs a supply of carbon dioxide, so perhaps a quarter to a third of the leaf is taken up by air spaces that act as a supply route. The consequence is that the inside of the leaf is full of surfaces that deflect the light again and again, so it bounces around instead of going straight through. Therefore, it makes sense for the cell to have chloroplasts distributed throughout the entire leaf, because it's pretty likely that some light will reach them eventually. But that's not all.

Perhaps the obvious strategy for a spinach plant would be to pack all the chloroplasts into the thin layer on the top surface of each leaf. However, it turns out that there's a maximum amount of light that each individual chloroplast can use. Bouncing the light around the inside shares out the available light so that more chloroplasts get a usable amount. And the final beautiful trick is when I said that chlorophyll 'mostly' leaves the green light alone, because when light has many opportunities for absorption as it's being bounced around so much, the green doesn't go to waste after all.

Each handful of fresh leaves is pale green in colour because of this internal architecture. Having all that structure means that more light (of all colours) bounces off the leaf, so I see something closer to white: light green.

Spending a while appreciating the nature of a leaf wasn't enough to stop me destroying it. Cooking spinach breaks down the cell walls so that the contents spills out, and the beeps when the microwave has finished indicate that the beautiful airy structure is ruined. Most light goes straight in and is absorbed by the chlorophyll, but doesn't come back out. This dark brooding green is the true colour of chlorophyll. And now I appreciate the bright colour of a growing leaf much more – that pale green shade is a delightful by-product of the elegance of a leaf's inner life.

Dr Helen Czerski is a physicist and BBC science presenter. Her book, *The Storm In A Teacup*, is out now (£8.99, Transworld).

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YOUR QUESTIONS ANSWERED

MAY 2017 | EDITED BY EMMA BAYLEY

What could we expect from a magnitude 10 earthquake?

RICHARD O'NEILL, GLASGOW

The 2011 Tōhoku earthquake off the coast of Japan created a tidal wave 40m high and shifted the entire main island of Honshu east by 2.4m. More than 127,000 buildings collapsed and almost 16,000 people died. This magnitude 9.1 earthquake only released about 3 per cent of the energy of a theoretical magnitude 10 quake. But there's an upper limit to how much energy you can store in the rocks. Very large earthquakes release more energy, but it is spread over a much longer section of fault line. It's doubtful that there are any fault lines on Earth big enough to release a magnitude 10 earthquake, but if one happened, you could expect the ground to shake just as hard as a magnitude 9, but for a lot longer – perhaps as much as 30 minutes. **LV**

PHOTO: GETTY

A tsunami roars into the city of Miyako, following 2011's earthquake

Why does yeast make bread rise?

NICHOLAS PEAT, KENDAL

Yeast is a single-celled fungus, and the cells are still alive when you mix them into the dough. The yeast releases enzymes that convert the flour starch into sugar, which the cells absorb and metabolise. This process releases CO_2 gas, which forms bubbles that become trapped in the stretchy dough. During baking, the oven's heat expands the bubbles even further. **LV**

Can different bird species understand each other's songs?

LEWIS MILLER, EXETER

Birdsong is more like music, rather than a true language. Birds sing to attract mates and defend territories, and the information contained in the song is basically just "Listen to my song, isn't it pretty?" or "Keep out, this area belongs to me!" Birds recognise the alarm calls of other species, but the song of a lovesick sparrow is of no interest to a pigeon, so there is no reason for them to pay attention. **LV**

Why are some plastics recyclable and others are not?

MARK WARMSLEY, SOUTHAMPTON

Most of the plastics we use are either thermoplastic or thermosetting. Thermoplastics include acrylics, nylon and polyethylene (polythene). As you heat them up they get soft, so they can be shaped into any form you like, which also makes them easy to recycle. Milk containers can be melted and reformed into furniture, plastic water bottles become fleece jackets, and hard bottle tops can get a new lease of life as storage boxes. Thermosetting plastics, like Bakelite or polyurethane, are different because they harden as you heat them. Once they have set, you can't melt them. This makes thermosetting plastics almost impossible to recycle. **ML**

Why do we dream more in some places than others?

CHARLIE MACK, UCKFIELD

Dreams most commonly occur during Rapid Eye Movement (REM) sleep, and are easier to remember if we wake during this stage of sleep or soon afterwards. Evolutionary theories emphasise the need to feel safe in order to lose vigilance and go to sleep, so we may sleep less well in a novel environment, or in rooms that are too hot, cold, noisy or uncomfortable. When we wake up more frequently during the night, we are more likely to remember our dreams. This gives us the impression that we dream more in certain places than others. AGr

How does the atmosphere rotate with the Earth?

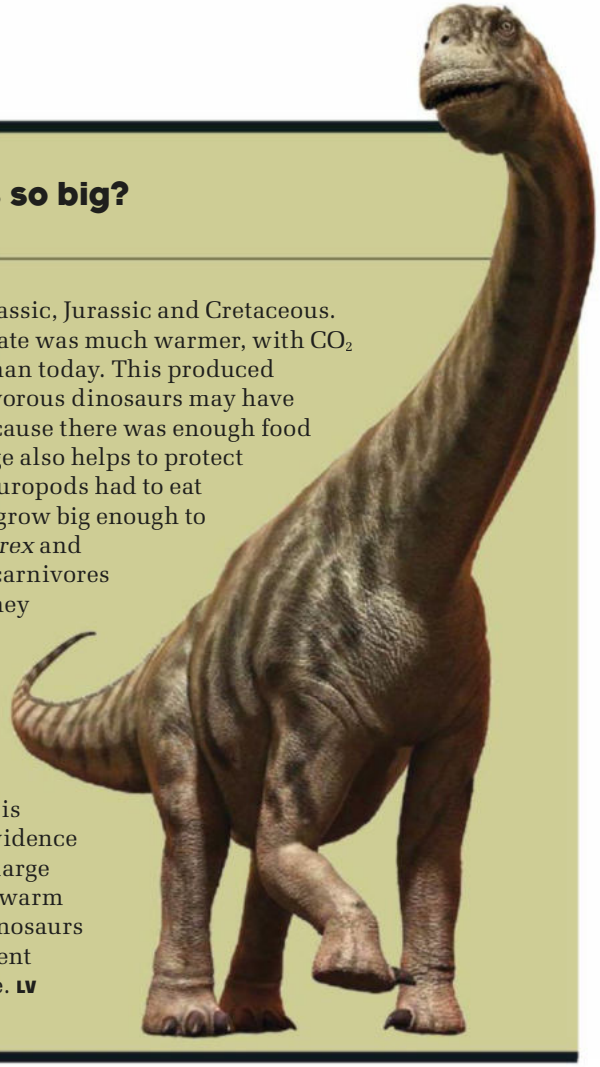
ROD LENNOX, COLCHESTER

Bound to the Earth by gravity, most of the atmosphere spins along with it as a result of friction with the ground and the viscosity or 'stickiness' of the different layers of air above it. Above 200km, however, the incredibly thin atmosphere actually spins faster than the Earth. The cause of this bizarre 'super-rotation' effect remains unclear, but has also been detected on Venus. RM

Why were dinosaurs so big?

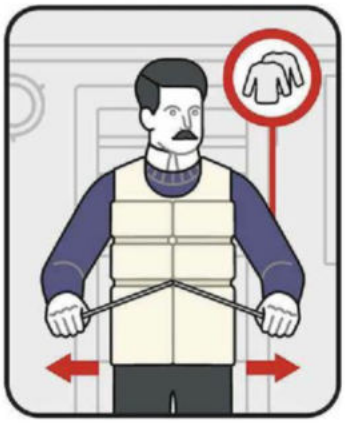
DAVID PAYLOR, OXFORD

Dinosaurs lived during the Triassic, Jurassic and Cretaceous. During these periods, the climate was much warmer, with CO_2 levels over four times higher than today. This produced abundant plant life, and herbivorous dinosaurs may have evolved large bodies partly because there was enough food to support them. But being large also helps to protect against predators. The giant sauropods had to eat plants as fast as they could, to grow big enough to be safe from carnivores like *T. rex* and *Spinosaurus*. Meanwhile, the carnivores were becoming larger just so they could tackle their enormous prey. Another possibility is that the herbivorous dinosaurs were ectothermic (cold blooded), and being huge helped them regulate their temperature. This theory is problematic though because evidence increasingly suggests that the large carnivores were endothermic (warm blooded), which means that dinosaurs would have evolved two different metabolic systems, side by side. **LV**



THE THOUGHT EXPERIMENT

HOW COULD YOU SURVIVE THE *TITANIC* DISASTER, IF THERE WAS NO ROOM IN THE LIFEBOATS?

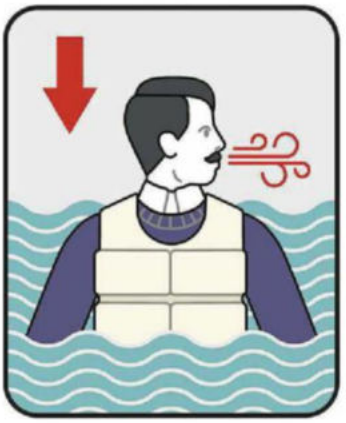


1. LAYER UP

Put on as much clothing as you can find. Wool repels water, creating insulating air pockets even when wet. A waterproof layer will trap air and help keep you afloat. Put on a life jacket or stuff your top with empty containers for buoyancy.

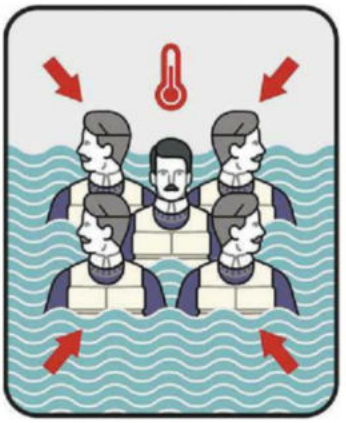
2. DON'T JUMP

Titanic's lifeboat deck was 17.6m above the water, and even a 6m jump is enough to compress your spine and break bones. Wait for the boat to sink first – the idea that you will be sucked under with it has been tested and disproved.



3. KEEP CALM

Breathe out as you hit the water to help counter the inhalation reflex caused by the cold shock response. Cold shock also causes a minute of hyperventilation. Once this subsides, you have 10 minutes before your limbs are too cold to move.



4. STAY WARM

Climb onto some debris. Even a cold wind won't freeze you as fast as the sea. If you can't find anything, huddle next to other survivors. In cold water it takes 15 to 60 minutes for your core temperature to drop below 28°C and stop your heart.

PHOTOS: GETTY X4, NASA ILLUSTRATIONS: RAJA LOCKEY

Why are some foods so widely disliked?

LIAM FARMER, NOTTINGHAM

Actually, a recent survey by *BBC Good Food* found that curry was both the 5th best loved and the 4th most hated, while fish was simultaneously the 2nd worst food and the 8th best. Liver is pretty much universally unpopular, but 30 years ago was more beloved. Intense food dislikes are often more about memories and associations than taste, so it may be that childhood experiences of school dinners are to blame for putting us off certain foods. **LV**

How large does an object need to be for something to orbit it?

VICKY ROBSON, LEEDS

There is no magic size or mass required for an object in order to have a 'satellite'. An 'orbit' occurs when the gravitational pull from a nearby object exactly matches the forward motion or momentum of the orbiting body. All objects (with mass) have gravity, however small they are. So, theoretically, any object can have another object in orbit around it; as long as that object moves slowly enough to be 'captured' by the gravitational pull. Of course, this is unlikely unless these objects are both moving extremely slowly, are close to each other, and are completely isolated from all other forces. **AGu**

IN NUMBERS

75

The number of litres of urine released by swimmers in a large swimming pool over a three-week period.

69

The percentage by which butterfly numbers have reduced in UK towns and cities over the last two decades.

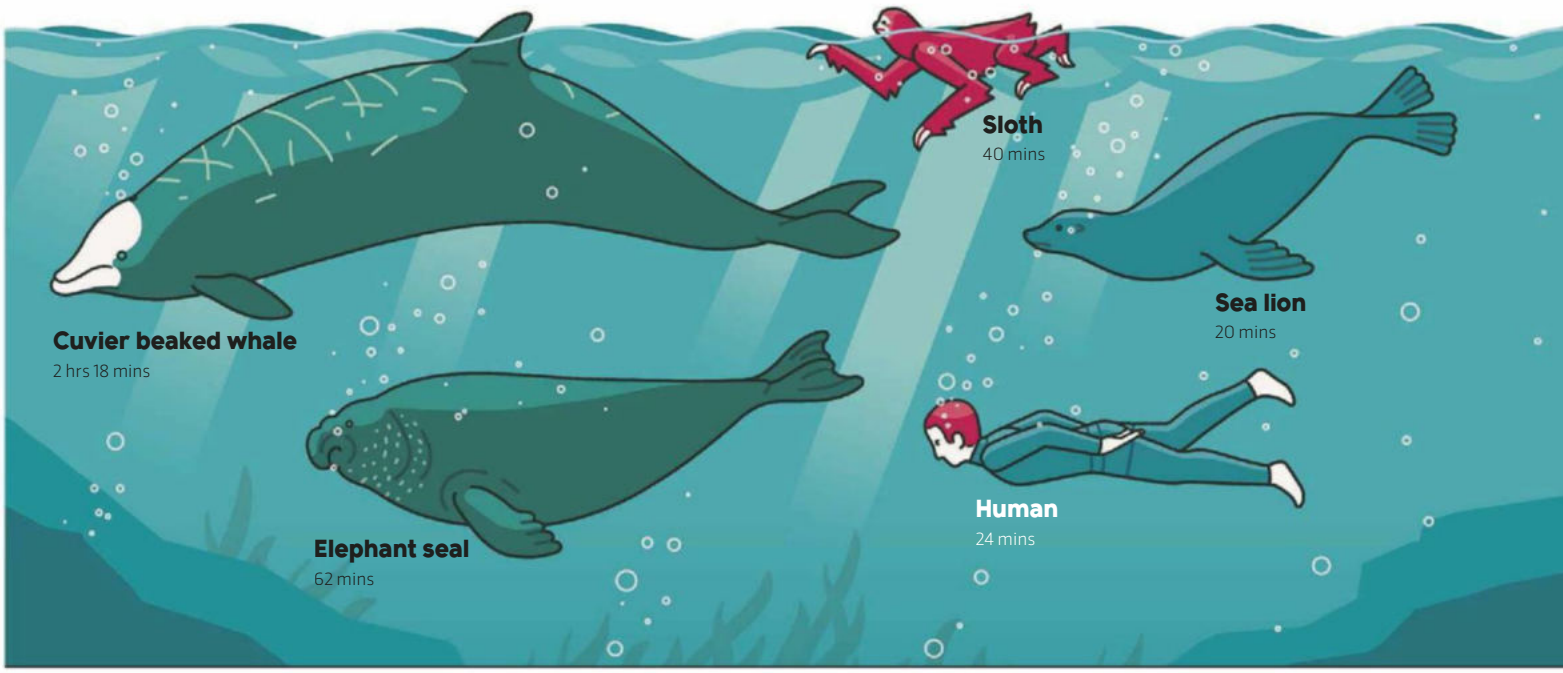
£57

The price a Japanese company charges for a 'fake friend' to come and pose with you in photos for two hours.

PHOTOS: GETTY X4 ILLUSTRATIONS: RAJA LOCKEY

What's the longest a human can hold their breath underwater?

JASON WOODS, DOVER

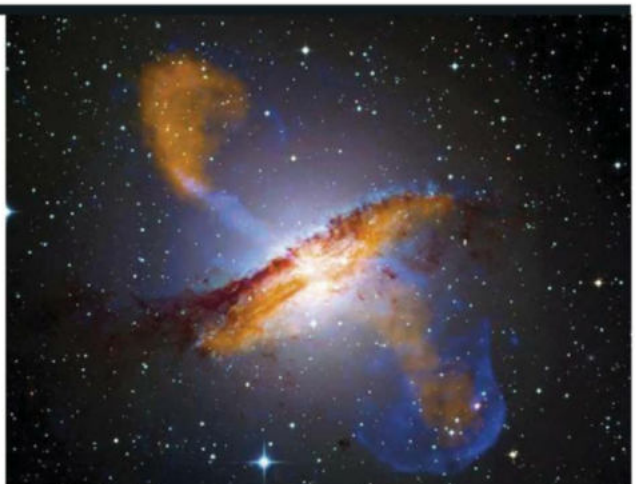


Are rainforests being replanted?

BILL ROBINSON, SLOUGH

Access to the Amazon was improved during the 1970s, indirectly leading to greater deforestation

A number of projects across the world aim to regenerate areas of rainforest. Brazil, for example, has committed to restoring 12 million hectares of forest by 2030. But even after several decades, replanted 'secondary' forest tends to have lower rates of biodiversity (particularly fewer large animals) than virgin rainforest, which houses a blend of species developed over hundreds of thousands years. Many replantation efforts focus on linking isolated patches of original forest with 'corridors' of restored forest. Deforestation is still a major problem in many parts of the world, so preserving existing rainforest is key to conservation efforts. **AC**

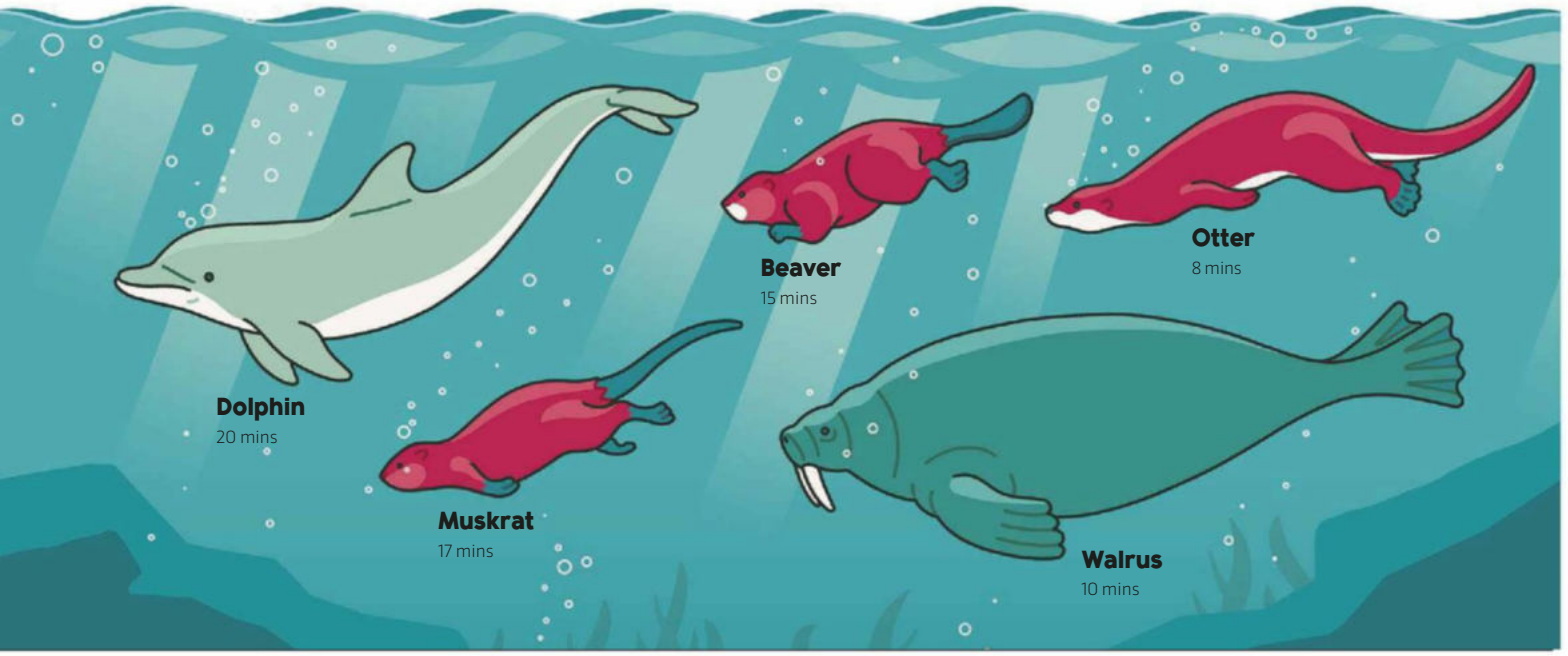


Why don't black holes ignite?

RAY SUDBURY, MANSFIELD

Physics cannot yet describe the kind of material that ordinary matter becomes once it is inside a black hole's event horizon. However, one thing is certain; matter does not survive in a form containing atoms. The usual particles of ordinary matter, electrons, protons and neutrons, have all combined into other particles or broken apart completely into quarks (or 'preons'). They may have been squeezed into a mere quantum probability, or not be 'matter' at all! Given that black holes are not made of regular matter, there is no process (nuclear fusion for example) by which they can 'ignite'. AGu

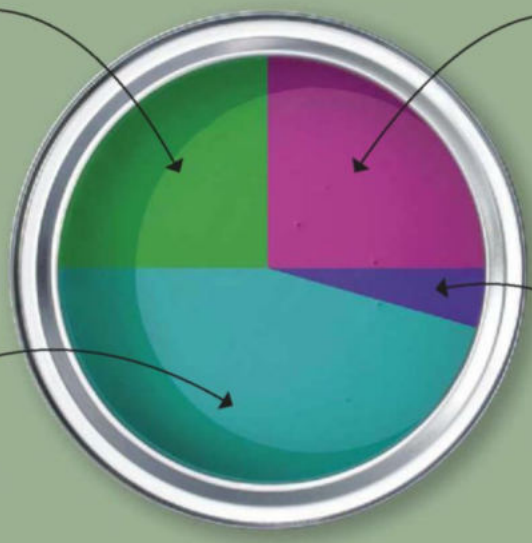
In all mammals, including humans, a dive reflex is activated when the face is submerged. The heart rate slows, and blood flow is diverted away from the limbs towards the head and torso. In aquatic mammals, this reflex is particularly well-developed. Without training, we can manage about 90 seconds underwater before needing to take a breath. But on 28 February 2016, Spain's Aleix Segura Vendrell achieved the world record for breath-holding, with a time of 24 minutes. However, he breathed pure oxygen before immersion.



WHAT'S IN...

...EMULSION PAINT?

Emulsion paint consists of tiny polymer particles within which the pigments are trapped. The particles are suspended in water, then as the paint dries the particles fuse together creating a film of paint on the wall. Once this happens the polymer can't be resuspended in water, which is why you can't wash a water-based emulsion paint back off the wall once it has dried. **ML**



PIGMENTS
25 per cent
Titanium dioxide is used for white, iron oxide for yellows, reds and browns, chromium oxide for greens, and carbon is used for blacks.

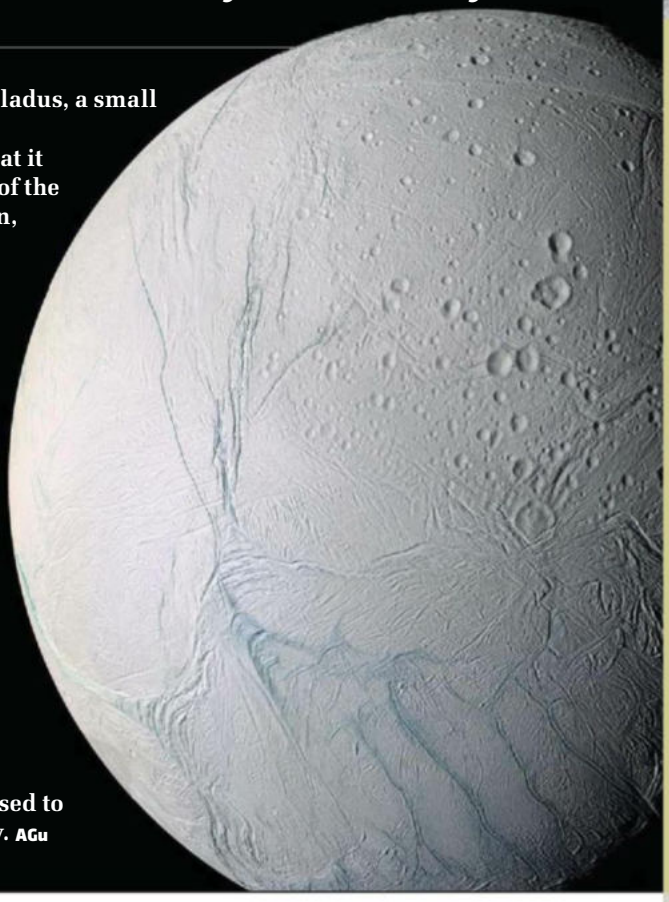
BINDERS
25 per cent
Acrylic or epoxy polymers surround the pigments and help them to bind to the wall.

SOLVENT
45 per cent
Nearly half of emulsion paint is made up of water.

OTHER ADDITIVES
5 per cent
These include biocides to stop algae and fungi growing on your walls.

What is the most reflective body in the Solar System?

ADAM WALLER, SHEFFIELD



This prize belongs to Enceladus, a small moon of Saturn. Recent measurements indicate that it reflects about 90 per cent of the incident light from the Sun, making it brighter than freshly fallen snow! The reason for this high reflectivity lies in the constant replenishment of the surface with ice particles vented from hydrothermal geysers. This implies that Enceladus has a subsurface liquid ocean that is heated by gravitational forces. This, combined with the presence of nitrogen and simple organic molecules, makes Enceladus a candidate for harbouring simple life forms. Several missions have been proposed to investigate this possibility. **AGu**

How do salmon find their way home?

ROD CLARKE, ISLE OF MAN

Salmon use the Earth's magnetic fields like a map. Unlike birds that can learn to navigate from their parents, salmon are left to their own devices from the moment they're born. They inherit a built-in magnetic sense from their parents and use it to navigate thousands of miles out to sea, where they grow up. Near the end of their lives, salmon remember the magnetic fields they encountered when they first entered the sea as youngsters and navigate their way back to the exact same stream where they were born, to spawn and die. **HS**

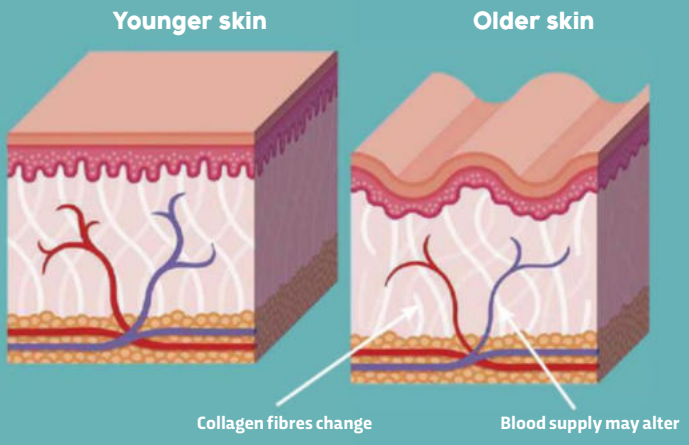
Love our Q&A pages? Follow our Twitter feed @sciencefocusQA

An Atlantic salmon battles against the water as it travels upstream to its spawning ground

PHOTOS: GETTY / APIS/NASA. ILLUSTRATIONS: RAJA LOCKEY

Why does skin wrinkle when you get older?

RYAN HAMMOND, US



Your skin isn't completely flexible and collagen fibres can get microscopic tears when they are folded or stretched. Mostly your body will repair this damage but sometimes the new collagen fibres will be too long and your skin will get a little baggier. Or they might be too short and pinch the skin slightly. Over time, these botched repairs accumulate at points where our face is frequently creased, such as the laughter lines round the eyes. **LV**

This cosy house took just 45 days to build using 3D printing

Could we 3D print a house?

MEGAN JACKSON, AGE 9, ABERGAVENNY

It's already happening! Scaled-up 3D printers that use concrete instead of plastic filament have been used to build wall sections for several years. And in 2016, Huashang Tengda (a Chinese construction firm) 3D printed an entire two-storey house. The steel reinforcing bars were still installed by hand, but then a concrete extruding robot printed the walls around them in just 45 days. **LV**

WHO REALLY INVENTED?

THE JET ENGINE

FRANK WHITTLE

HANS VON OHAIN

The basic idea of creating motion by directing a jet of fluid in the opposite direction dates back to ancient times. In the 1st Century AD, the Greek mathematician Hero of Alexandria described a device propelled by squirting steam out of two opposing nozzles. But it's doubtful it ever worked as the jets were probably too weak to overcome friction between its various components. In 1922, French engineer Maxime Guillaume was granted a patent for a simple jet engine. While never built, it had the right idea. It consisted of a series of turbines to compress air, which was then mixed with fuel and ignited. The resulting rapidly expanding gas produced thrust.

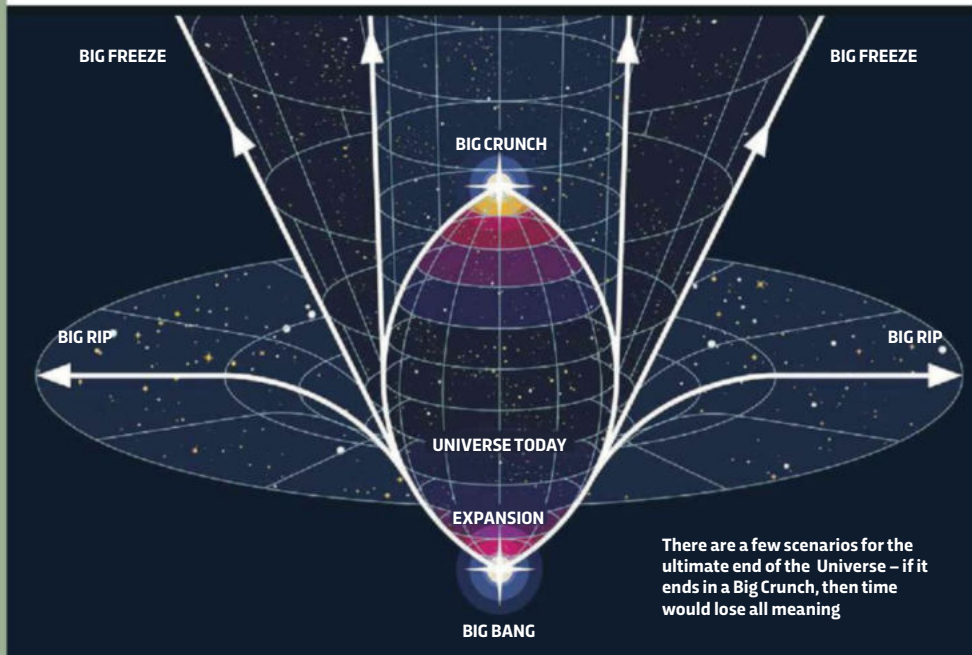
The first to succeed in making this approach work was a young RAF engineer named Frank Whittle. In the 1920s, he devised an arrangement of turbines and compressors he claimed would produce enough thrust for aircraft propulsion. The UK Air Ministry disagreed, however, leading him to set up his own company, which created the first working jet engine in 1937. By then, German physicist Hans von Ohain had hit on a similar design, allowing him to beat Whittle to the first actual flight of a jet aircraft – the Heinkel He 178 – in August 1939.

Hero of Alexandria with a steam-powered device

Are wood-burning stoves environmentally friendly?

KEVIN GREEN, BURSCOUGH

Wood-burning stoves offer a low-carbon alternative to heating your home using fossil fuels. Trees absorb carbon dioxide as they grow, which is returned to the atmosphere when their wood is burned. If you source your logs or wood pellets locally, a wood stove is virtually carbon neutral. The flipside is that wood fires produce vast quantities of particulate matter, tiny fragments of soot like those emitted by diesel cars. These contribute to climate change but can also cause breathing problems or even cancer in humans. In urban areas particularly, wood-burning stoves are therefore not the greenest choice. **AC**



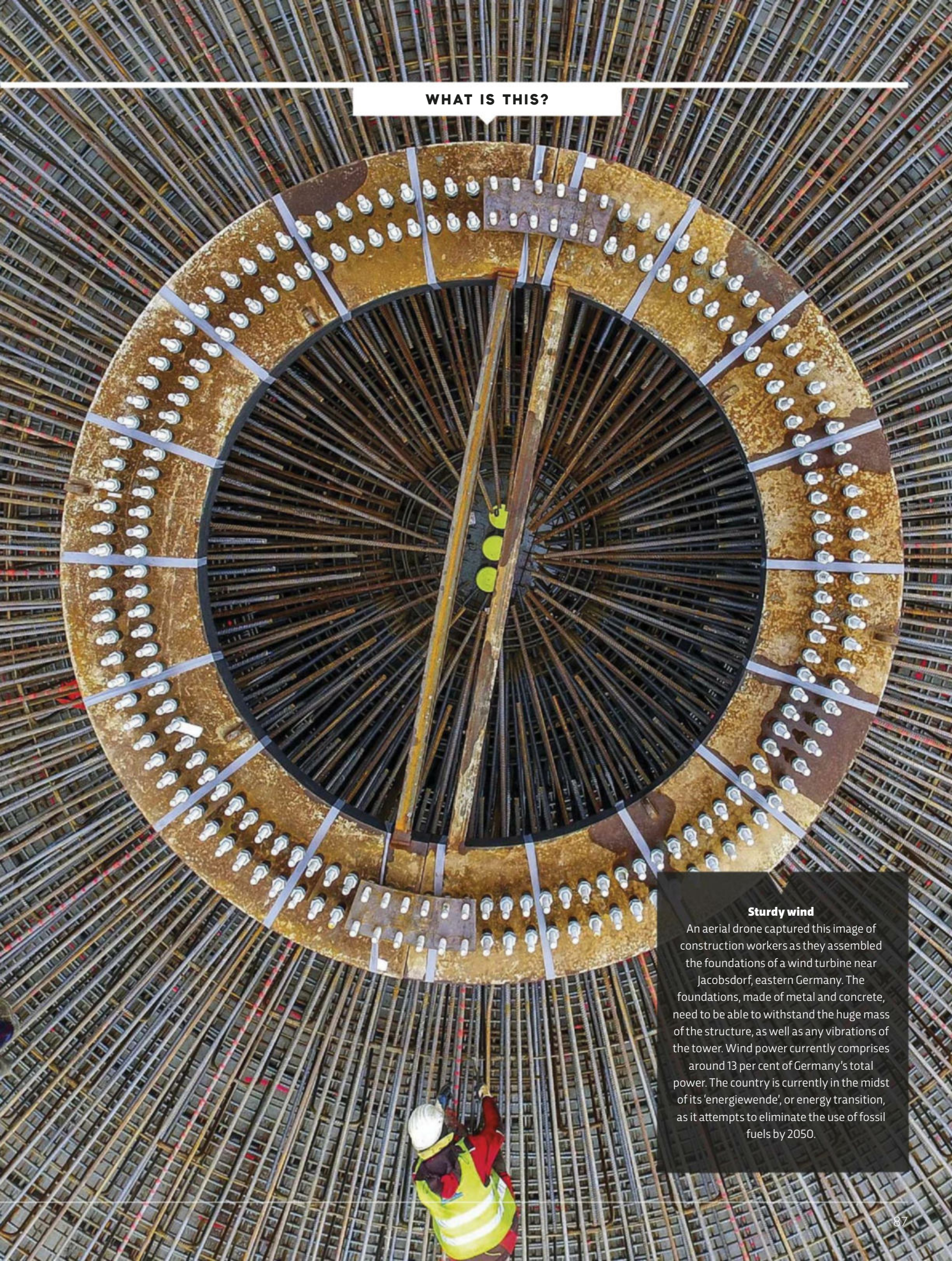
There are a few scenarios for the ultimate end of the Universe – if it ends in a Big Crunch, then time would lose all meaning

Will time ever end?

TERRY STANTON, BY EMAIL

According to Einstein's General Relativity, which is our best current description of space and time, the only place where time – and also space – ends is in a so-called singularity. This involves gravitational forces becoming so intense that space and time lose all meaning. While this is a theoretical possibility if the Universe collapses into a 'Big Crunch', observations suggest the current cosmic expansion will continue indefinitely. RM

PHOTOS: GETTY X4, SMITHSONIAN NATIONAL AIR AND SPACE MUSEUM



Sturdy wind

An aerial drone captured this image of construction workers as they assembled the foundations of a wind turbine near Jacobsdorf, eastern Germany. The foundations, made of metal and concrete, need to be able to withstand the huge mass of the structure, as well as any vibrations of the tower. Wind power currently comprises around 13 per cent of Germany's total power. The country is currently in the midst of its 'energiewende', or energy transition, as it attempts to eliminate the use of fossil fuels by 2050.

This whooping crane chick is being fed by its disguised surrogate 'mother'

How small can a population be and still survive?

AURIOL MATTHEWS, TWICKENHAM

We often hear of species being on the brink of extinction, with reported remaining numbers from several thousand to a few dozen. But their fate depends on whether they can be protected from three key threats. The most potent threat is environmental, such as changes in food and water supplies. The other two are disease and the emergence of a new predator. Populations below 10,000 can be quickly wiped out by such challenges. Below a few hundred, species become vulnerable to genetic inbreeding, while species with fewer than around 50 members can be wiped out by otherwise normal blips in birth and death rates. Even then, their fate is not sealed: conservation efforts have rescued species such as the whooping crane of North America, which in the 1940s numbered fewer than 23 individuals. **RM**

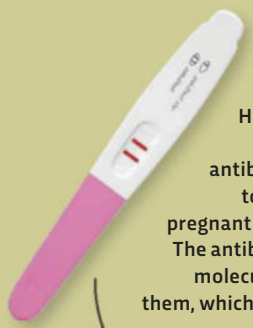
What causes sleep paralysis?

MARY SMITH, LONDON

During rapid eye movement (REM) sleep, our body is paralysed to stop us from acting out our dreams. When sleep paralysis occurs, features of REM sleep are continuing into our waking lives. In particular we are unable to move and sometimes experience hallucinations. Both genetic and environmental factors are at play. Circadian genes might be important, although more research is needed to specify which genes are involved. As for environmental influences, it appears that anything that might disrupt our sleep – including stressful life events and alcohol use – can be a risk for sleep paralysis. AGr

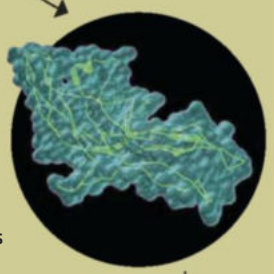
WHAT CONNECTS...

...PREGNANCY TESTS AND FROGS?



1. Home pregnancy tests use antibodies that bind to hormones in a pregnant woman's urine. The antibodies have dye molecules attached to them, which create a visible line on the test.

2. The hormone being detected is called human chorionic gonadotropin, or HCG, which the placenta secretes once a fertilised egg has implanted. It is detectable from the day the woman's period is due.

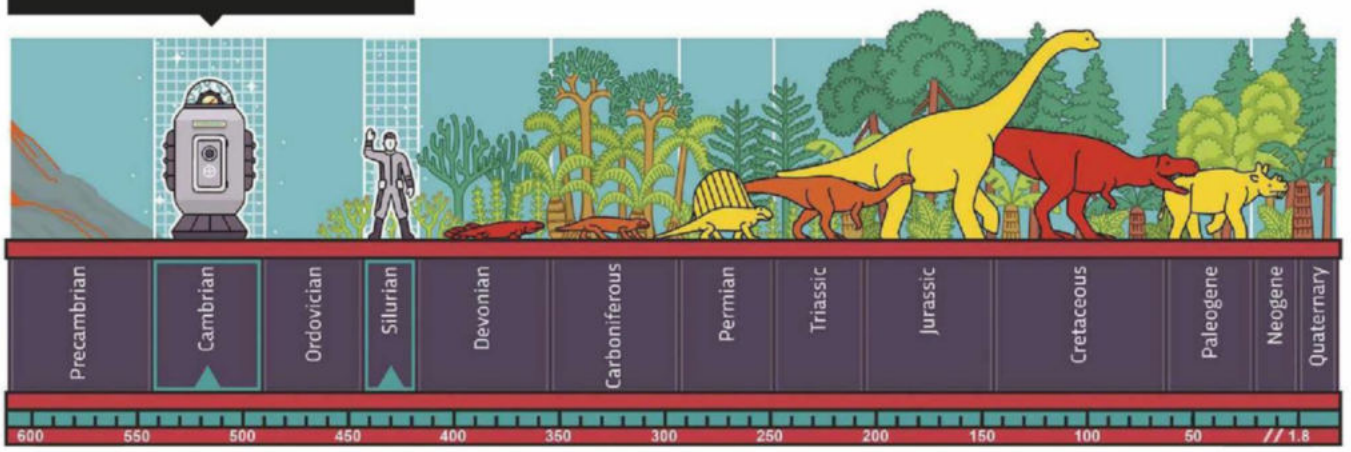


3. Although HCG is specific to humans, other vertebrates have similar gonadotropin hormones that regulate their reproductive cycle. HCG collected from humans is used by vets to induce ovulation in horses.

4. But it isn't only horses that HCG can affect. In the 1960s, clinical pregnancy tests involved injecting a woman's urine into the leg of a live African clawed frog. If the frog laid eggs the next day, the woman was pregnant.

PHOTOS: GETTY X6, SCIENCE PHOTO LIBRARY ILLUSTRATIONS: RAJA LOCKEY

QUESTION OF THE MONTH



What is the earliest, geologically, that humans could have survived on Earth?

JOHN BRODERICK, BLACKBURN

If we used a time machine to travel back to a prehistoric period, the earliest we could survive would be the Cambrian (around 541 million years ago). Any earlier than that and there wouldn't have been enough oxygen in the air to breathe. At the beginning of the Cambrian, the air at sea level would have felt like base camp at Mount Everest, but the climate was milder and more uniform than today. A bigger problem would be finding something to eat because there were no land plants or animals. You'd need to find a way of catching trilobites and other strange-looking shellfish, without wood to make a spear or plant fibre to make a fishing net. And you'd have to eat them raw, unless you could find a way to extract oil from these animals, or burn dry seaweed. For a more comfortable existence, you might be better off skipping ahead 100 million years to the Silurian. This had slightly more oxygen and a warmer climate, as well as simple land plants and the first bony fish, which might have been more palatable. Unfortunately, you would have to share the land with prehistoric millipedes and spider-like creatures. **LV**

WINNER!

John Broderick wins a Plustek ePhoto Z300 scanner (£169, **plustek.com**). It is designed to scan photos so you can save them on your computer or share them via social media. It's easy to use and takes just a couple of seconds per print.

Is Mars really heating up quicker than Earth?

TONY BRADSHAW, BUCKINGHAMSHIRE

Recently, debate about global warming on Earth has been intensified by the observation that Mars appears to be undergoing a period of climate change. It has been suggested that warming is therefore a result of natural processes rather than human activity. However, climate change on Mars is mostly determined by changes in the tilt and shape of its orbit and the only reliable evidence merely indicates that Mars ended its most recent ice age about 400,000 years ago. Although some studies in the 2000s purportedly showed evidence of climate change on Mars, these were shown to be either localised effects due to Martian 'weather' and dust storms rather than 'climate'. The most recent studies show that there have been no significant changes in the average Martian temperature since at least the time of the Viking landers in the 1970s. So there is no evidence that Mars is actually heating up at all. AGu

NEXT ISSUE:

Do animals have blood groups?

Why do jokes make us laugh?

Can you turn glass back into sand?

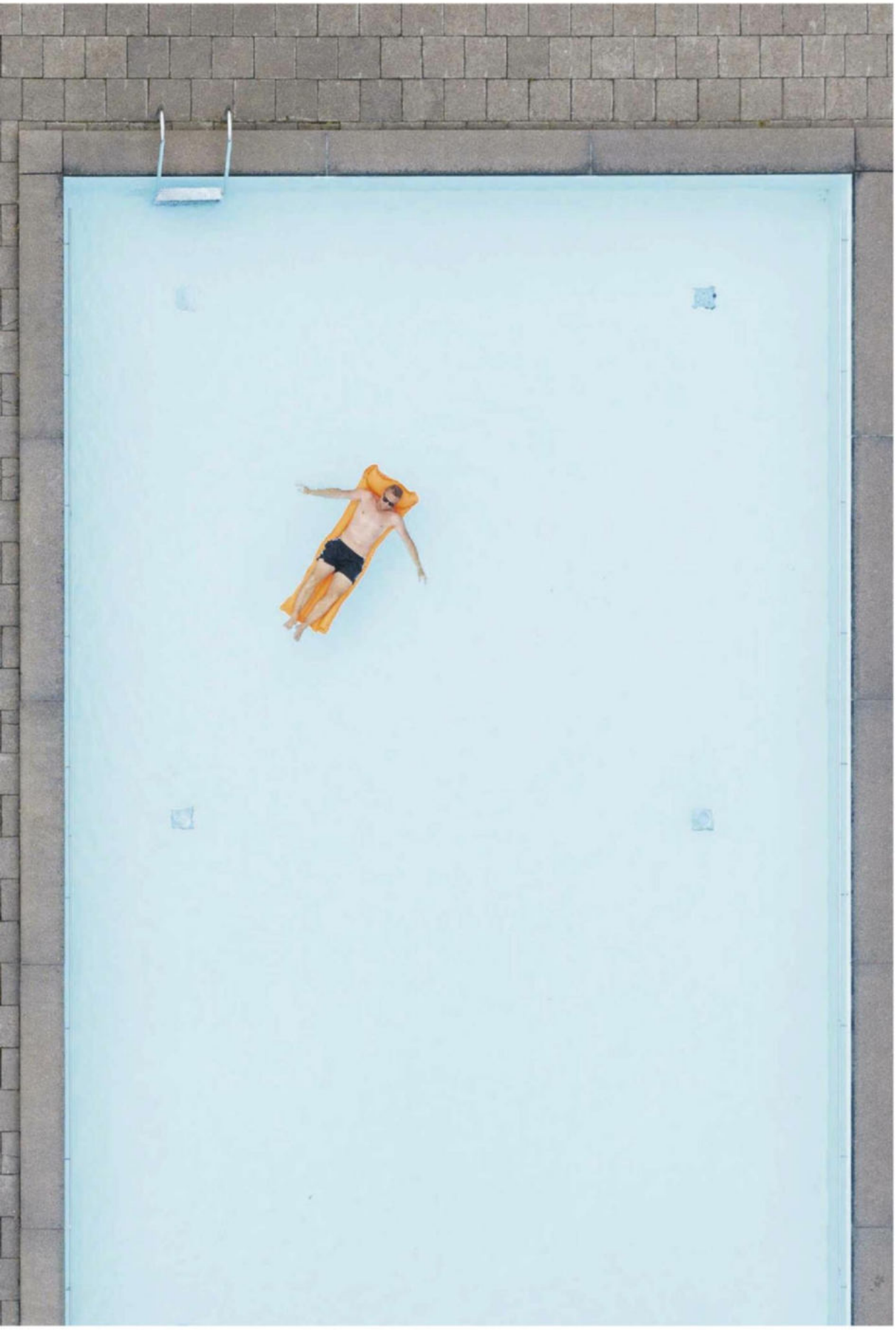
Email your questions to **questions@sciencefocus.com** or submit online at **sciencefocus.com/qanda**

OUT THERE

WHAT WE CAN'T WAIT TO DO THIS MONTH

MAY 2017 | EDITED BY JAMES LLOYD

PHOTO: ANDERS@ANDERSA.COM/THAMES & HUDSON



01

TAKE A DRONE'S EYE VIEW

DRONESCAPES EDITED BY AYPERI KARABUDA ECE
OUT NOW (£24.95, THAMES & HUDSON).

Back in the day, you would have needed your own helicopter or an extremely tall tripod if you wanted to take photos from the sky. Now, all you need is a drone.

Thanks to the tumbling prices of camera-equipped quadcopters, more people than ever are getting into aerial photography, peering down from previously inaccessible vantage points. A new book collects together the pick of the bunch, compiled from popular drone photography website Dronestagram.

Highlights include this award-winning shot of a swimming pool in southern Sweden, taken by Anders Andersson (and starring his neighbour). Elsewhere, there are gorgeous shots of famous landmarks, aerial views of the animal kingdom, profiles of notable drone photographers, and a user guide for newcomers to this burgeoning art form.

02 COOK UP SOME GRUB(S)

With meat consumption taking its toll on the environment, we might soon need to turn to insects as an alternative foodstuff. Here are three recipes to inspire you, courtesy of Sardinian chef Roberto Flore and his colleagues at Nordic Food Lab

APPLES AND ANTS

SERVES 4

150ML WATER
20ML LEMON JUICE
500ML APPLE JUICE
5ML ANTY GIN (AVAILABLE FROM CAMBRIDGEDISTILLERYSHOP.CO.UK)
3 FRESH JUNIPER BERRIES
380G APPLES
800G RHUBARB
300ML FILTERED WATER
1G LIQUORICE POWDER
7G LIQUORICE SYRUP
3G ANGELICA SEEDS
SEASONAL HERBS (WOOD SORREL, LEMON VERBENA, NASTURTIUM, ETC)
15 RED WOOD ANTS (*FORMICA RUFA*)

Pour the water, lemon juice, apple juice and gin into a bowl. Add the juniper berries. Using an apple corer, cut the apples into 12 cylinders of different lengths, then use a knife to cut the ends flat. Put the apple cylinders in the bowl to infuse in the liquid, and chill in the refrigerator for four hours. Meanwhile, wash and remove the leaves from the rhubarb stalks, then juice the stalks in a juicer. Pour the juice into a pot and bring to the boil, skimming off any foam. Turn off the heat and strain the liquid through a thin colander into a bowl. Add the liquorice powder, liquorice syrup, filtered water and angelica seeds and mix together. Pour into a plastic container with a lid and keep in the refrigerator until ready to serve. Use a small pasta cutter to cut the seasonal herbs into small, round confetti. Pour the rhubarb juice into bowls. Place three apple cylinders of various heights in the middle of each bowl and top with the confetti plus one or two ants. The ants add an intensely sour and citrussy note to the dish.

PHOTOS: CHRIS TONNESEN/PHAIDON PRESS

PEAS 'N' BEES

SERVES 4

500G FRESH PEAS
500ML COLD FILTERED WATER
1 LITRE OF WATER FOR BLANCHING AND CHILLING
3G FRESH LOVAGE LEAVES
30G BEE LARVAE

Blanch the peas in salted water for one minute, then cool in salted ice water and dry. Mix the peas with the filtered water, season with salt and pepper to taste, and add the lovage leaves. Blend using a standard hand blender. Pass through a colander. Blanch the bee larvae in a small pot of salted water for one minute. Drain using a small metal sieve. To serve, warm the pea cream gently in a pan, making sure it doesn't boil. Pour into bowls and top with the larvae. The larvae offer a slightly sweet, umami flavour.

HORNET HIGHBALL

SERVES 1

ICE CUBES
2ML JAPANESE GIANT HORNET LIQUOR (MADE FROM FERMENTED GIANT HORNETS)
60ML WHISKY OF CHOICE
150ML SODA WATER OR SPARKLING WATER
1 TWIST OF LEMON PEEL

Half-fill a highball glass with the ice cubes and add the hornet liquor with a pipette. Pour in the whisky of your choice, followed by the soda water and the lemon peel. Stir and serve immediately. The hornet liquor provides a musky taste. Yum!

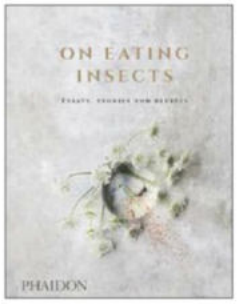
WHY EAT INSECTS?

"Eating insects makes more environmental and economic sense than eating traditional livestock, but is this enough for us to start introducing insects into our diet in Europe? I don't think so.

"I was extremely fascinated to discover that there are many reasons why people eat insects around the world, but only one always emerges as fundamental: insects taste good. Most of them are collected directly from the wild and cooked as a fresh, seasonal ingredient. As a chef, I see edible insects as the key to starting a conversation about the food we eat, as we look to embrace different types of food from different cultures. We can use them as a starting point to develop a more profound relationship with what's on our plate, and a more complex understanding of what a sustainable food should be.

"Eating insects might not save the world, but it certainly won't do any harm. And they taste better than you might think!"

Roberto Flore, head of culinary research and development at the Nordic Food Lab.



ON EATING INSECTS: ESSAYS, STORIES AND RECIPES
BY JOSH EVANS, ROBERTO FLORE, MICHAEL BOM FRØST AND NORDIC FOOD LAB
OUT 1 MAY (£39.95, PHAIDON).

03 CREATE A MUSEUM

RE-MAKING NATURE WEEKEND, WELLCOME COLLECTION
4–7 MAY,
FREE DROP-IN.
BIT.LY/REMAKE_NATURE

If you've ever wanted to see one of your prized possessions on display in a museum, here's your chance. The Wellcome Collection is looking for objects for an upcoming exhibition that explores the ways in which we relate to nature in the modern world.

From Thursday 4 to Sunday 7 May, members of the public are invited to bring along items that represent their personal connections to nature. They'll have their objects captured on camera and get to record the stories behind them, and there'll also be talks and activities, plus appearances from the BBC's *Springwatch* team. Some of the objects will then be chosen by curators to go on display in *A Museum of Modern Nature*, opening at the Wellcome Collection on 22 June 2017.

"Nature means different things to different people," says exhibition curator Honor Beddard. "We hope that the objects and stories that are selected will be surprising, moving, funny and perhaps sad, and that ultimately they will reveal a modern story of nature as told by the public."

PHOTOS: THE BOARD OF TRUSTEES OF THE SCIENCE MUSEUM, FRAN MOORE

04 GO FOR A PINT

PINT OF SCIENCE FESTIVAL
15–17 MAY, NATIONWIDE.
PINTOFSCIENCE.CO.UK

What's that, you say? Science? In a pub? Don't mind if we do. The Pint of Science festival returns this year for another three days of mind-expanding talks down your local.

Started in 2013 by two researchers at Imperial College London as a way of bringing scientists and their research out into the public domain, this year's festival will take place in over 100 cities across four continents. Participating UK cities include London, Bristol, Exeter, Glasgow, Manchester, Cardiff, Hull, Newcastle, Norwich, Nottingham, Portsmouth and Sheffield. There'll be expert talks on everything from neuroscience and astronomy to zoology and robotics, and you don't need any prior knowledge – just an open mind and a can or bottle of your favourite drink. Visit **pintofscience.co.uk** to find out what's on near you.

PHOTOS: GETTY, BBC X3, NICK RUTTER

05

MEXICO: EARTH'S FESTIVAL OF LIFE
BBC TWO IN MAY.
FOR DETAILS, CHECK
RADIOTIMES.COM

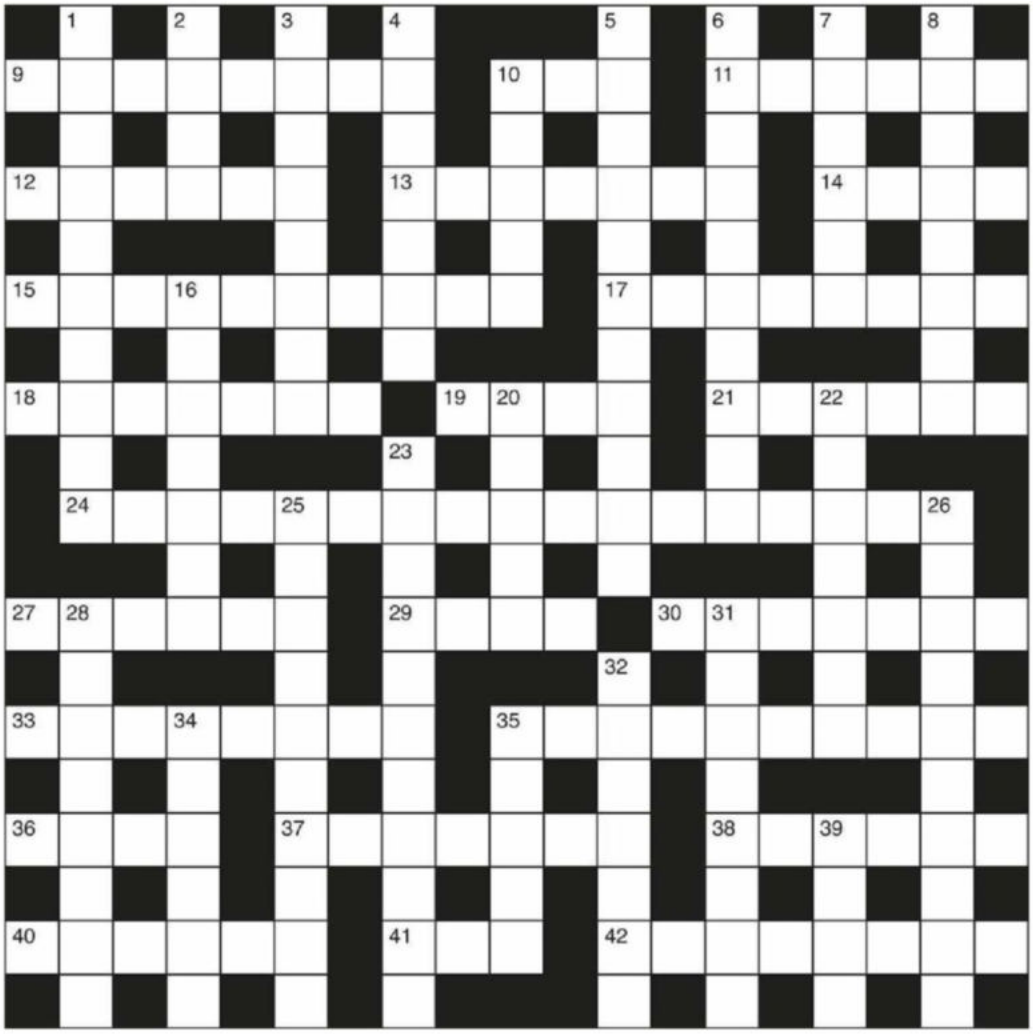
MARVEL AT MEXICO

Think of Mexico and its bustling cities probably spring to mind. But this country, rich in culture and history, is also one of the most biodiverse places on Earth. Sitting at the junction of the Americas, it's a land where the temperate north meets the tropical south, creating a stunning mosaic of habitats.

A new three-part series on BBC Two this May shines a light on three diverse Mexican worlds. We'll discover the mountainous spine of the country (the Sierra Madre), the tropical forests of the Yucatán Peninsula (complete with a secret underworld of flooded caves and passageways), and the prairies and deserts of the burning north.

Along the way, we'll meet the resplendent quetzal bird, a family of Mexican black bears, and millions of monarch butterflies overwintering in the mountains. There's also a chance to join the spellbinding Day of the Dead celebrations in Oaxaca, and find out how tequila is made. ¡Arriba!

SCIENCE CROSSWORD
GIVE YOUR BRAIN A WORKOUT



DOWN

1 Musical season for timekeeper (10)
2 Technophile of keener demeanour (4)
3 Document's title gets female in trouble (8)
4 Soviet soldiers have two types of ant (3,4)
5 A recent horn composition fills a cavity (11)
6 Aid calico design with variable plant product (6,4)
7 At home, enjoy old dye (6)
8 Grip had noise improved (8)
10 A little bit republican at a city (5)
16 Change a topic to a type of food (7)
20 Firm about communist beliefs (5)
22 False argument in ship so affected Frenchman (7)
23 Screen shape makes for static opera performance (6,5)
25 Animals gently hold a digital game (4,6)
26 Ration isn't involved in change (10)
28 Flying into turbulence after a woman gets answer (8)
31 Philosopher sent Sue off to get Greek character and dog (8)
32 Pass mob disrupting old city (7)
34 Noble time (6)
35 Heard a cab show lack of coordination (5)
39 Eccentric mode of building (4)

ACROSS

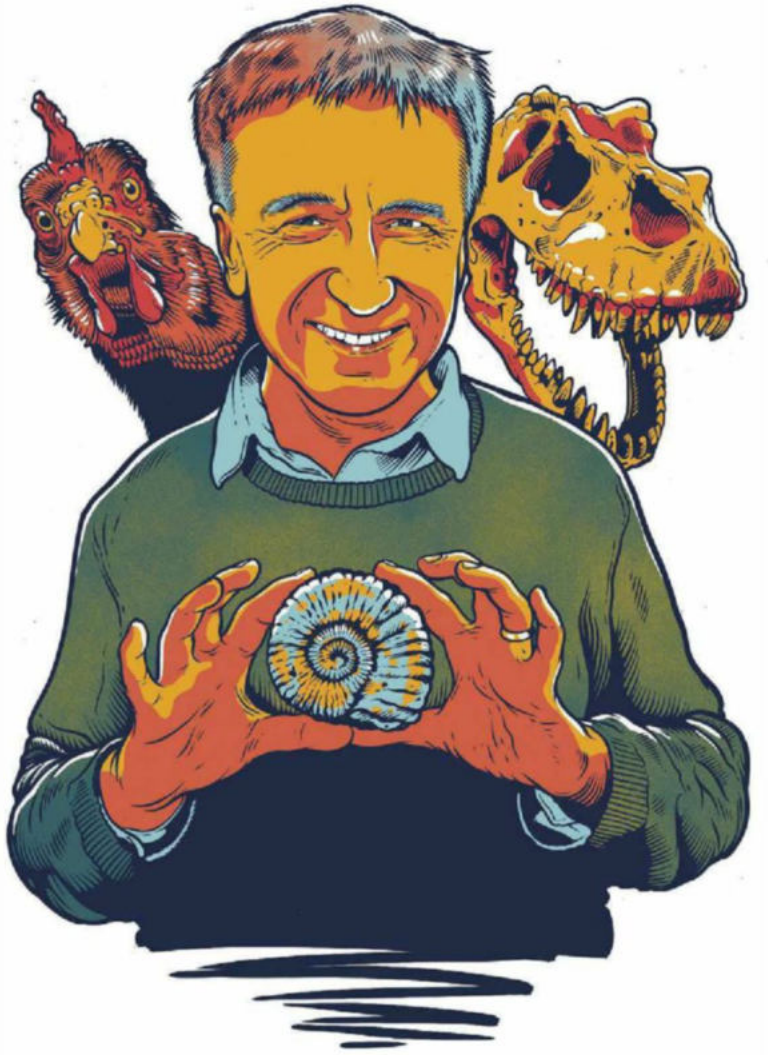
9 Cook tile formed in hard plastic (8)
10 Tune that we can breathe (3)
11 Texan adult has a luxury mansion (6)
12 Connection to a game (6)
13 A student indifferent about hard liquor (7)
14 Holly, say, is initially finding 50 old (4)
15 Halt, hop around and aim to solve conjunctivitis (10)
17 Death of crones is unfortunate (8)
18 Dire problem, having to choose power of lens (7)
19 Spots cane construction (4)
21 Following without hard shell (6)
24 City, former location of pig (10,3,4)
27 Blast a formation of rock (6)
29 Robe worn by Archbishop of York (4)
30 Claimed to be working in base ten (7)
33 Fellow performed in a cult film when released (5,3)
35 Quantity – a huge number of particles (6,4)
36 Party animal (4)
37 Language from a father gets artist to laugh (7)
38 Modernise with tea and pud combination (6)
40 Lads worried about gold at the back (6)
41 Current victory unknown to climber (3)
42 Benefit with new mule – an infrequent event (4,4)

ANSWERS

For the answers, visit **bit.ly/BBCFocusCW** Please be aware the website address is case-sensitive.

"If you spread all human-made things across Earth's surface, we'd be knee-deep in the stuff"

Geologist **Jan Zalasiewicz** chats with **Helen Pilcher** about living in a henhouse, weighing the Anthropocene and fossilising Mozart



What got you into rocks?
When I was a kid the *Eagle* comic ran a serialisation of Conan Doyle's *The Lost World*. The sheer fascination of a world that was so distant and exotic made quite an impression. After that, I started collecting fossils. I spent a couple of summers working on the collections at the Ludlow Museum, where people were so knowledgeable and generous with their time, it made me realise that this was the area I wanted to work in.

I hear you used to live in a chicken shed, is this true?
For my PhD, I studied the ancient rocks of North Wales. When I first arrived, I had nowhere to stay, so I knocked on the door of a local farm. The lady of the house gestured to a little caravan, full of hens, and said I could stay there. The chickens were evicted, the caravan was cleaned and I – and the farm cat – moved in.

How did you go from working on the deep past to thinking about the future?
By accident! I approached a magazine to ask if I could write about some obscure geochemistry that I found fascinating. The editor wasn't so keen but asked me to propose something different. I chanced on the idea of applying what I had learned from the deep past, to predict what will be left in the future long after humanity has disappeared, and wrote about that.

What will the post-human fossil record look like?
Lots of things will be left behind. If you take a city in a place where it can be buried – say New Orleans on the rapidly sinking Mississippi delta – lots of the substructure will be buried, squashed and compressed. Concrete pilings can preserve just as well as the average trilobite [an extinct group of marine arthropods].

Ah... the trappings of the Anthropocene.
Indeed. The Anthropocene is proposed as a new geological epoch where humans are impacting on the planet in a way that will last for millions of years. I'm chair of the group that is working out how real all of this is.

And how real is it?
Based on the changes scientists are observing in rocks, glacial ice and other natural phenomena, most people think it is. It really took off in the last 70 years, as that's when most of the fly ash, concrete, plastic and other human-made substances have been produced.

How much have humans changed the face of the planet?
One way to quantify it is to add up the mass of all the houses, factories, roads, fields and other human-made things. It weighs about 30 trillion tonnes, that's around 50 kilos per square metre. If you spread it evenly across the Earth's surface, we'd be knee-deep in the stuff.

That's a bit grim. Any good news?
Things like 78rpm records and CDs will be preserved in the fossil record. I like to think of a geologist in the future cleaning one of these fossils up and discovering Duke Ellington or Mozart. It adds a whole new dimension to rock music!

Prof Jan Zalasiewicz is a geologist at the University of Leicester. He is part of a community of scientists who are working to get the

DISCOVER MORE

To listen to an episode of *The Life Scientific* with Prof Jan Zalasiewicz, visit **bbc.in/2nfhZ9L**

NEXT ISSUE: DR ANDY FARKE

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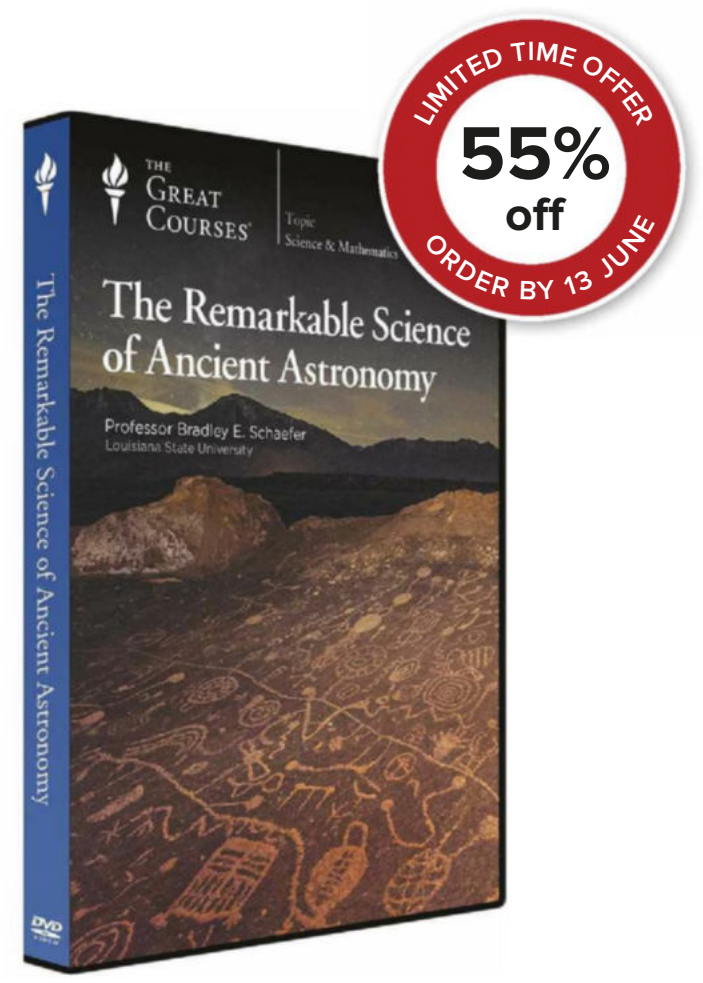

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